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APPENDIX C

Calculation of Separation Distances

Between SkyBridge Earth Stations and Fixed Services Point-to-Point Microwave Links

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prepared by

COMSEARCH

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Calculation of Separation Distances between SkyBridge Earth Stations and Fixed Services Point-to-Point Microwave Links

1. Background The purpose of this task was to calculate separation distances required for successful interference-free coordination of the proposed SkyBridge earth stations that will operate its down-link receivers in the Fixed Services (FS) commercial 11-GHz Band. The calculations were performed utilizing typical operational parameters for the FS Links taken from the Comsearch databases. These included both Analog and Digital links. The parameters for the SkyBridge earth stations were taken from material SkyBridge submitted to the Federal Communication Commission (FCC) and other technical material SkyBridge has published publicly for the system. A list of these documents is included as an Appendix to this report. The calculation methods used in this effort, both by computers and manually were derived from National Bureau of Standards (NBS) Technical Note 101, International Telecommunication Union (ITU) Recommendation ITU-R SF.1006 and textbooks that deal with propagation and shielding.

2. Parameters The parameters used to describe the SkyBridge earth stations are listed below:

Antenna Size:	2.5 and 4.5 meter
Antenna Gain @ 10.7 GHz :	48.2 and 53.2 dB
½ Antenna Beam Width @ 3/15 dB points:	.39/.78 and .09/.18^0
Antenna Centerline:	3.1 m or 10 ft./ 4.1 m or 13.5 ft.
Side Lobe Characteristics:	32 – 25*log (Θ) for values of Θ that produce side lobes equal to or greater than –10 dB. For greater values of Θ, the side lobe level = -10 dB
Minimum Elevation Angle:	6^0
Horizon Gain at the Minimum elevation Angle:	+ 12.5 dB
Maximum Elevation Angle:	90^0
Horizon Gain at the Maximum Elevation Angle:	- 10 dB
System Receiver Frequency:	10,700 MHz
Receive System Noise Temperature:	190^0 K
Interference Threshold Long Term:	- 154.3 dBW/MHz
Interference Threshold Short Term:	- 143.0 dBW/MHz

The interference thresholds were calculated using the Equations (3) for P_1= 20% (long-term) and (4) for $P_2|n_2$ = 0.0025% (short-term) in the ITU Recommendation SF.1006.

Parameters for the terrestrial microwave stations may vary over a wide range The values used in the calculations are listed below:

Antenna Size:	0.5 to > 4 meter
Antenna Gain @ 10.7 GHz	33.0 to > 51 dB
Antenna Centerline:	7.0 to > 150 meter
System Modulation:	Analog or Digital
Bandwidth:	1 to 80 MHz

Transmitter Power Output:	.001 to 10 Watts
Feeder Loss:	3.3 dB per 30 meters

3. Calculation Approach: The calculation approach utilizes the Comsearch standard coordination procedures. These procedures utilize the formulas derived from NBS Technical Note 101. All of the calculations utilize a large range of parametric values so the levels of the interference results can be evaluated with respect to the parameters.

Propagation Model Assumptions:

- Free space loss for line of sight conditions, for greater distances modified as appropriate by over-the-horizon considerations
- FS antenna height for calculations 50 meters, Diameter 4 meters, Gain 51 dB
- Minimum separation distance 1 kilometer, maximum separation distance 350 kilometers
- Gateway antenna center line heights heights, 3.1 and 4.1 meters (2.5 and 4.5 meter antennas
- Ground elevation is the same for both the FS and Gateway antennas
- Frequency of operation 10,700 MHz, wavelength = 2.8 cm
- FS transmitter output 1 Watt
- Transmit Spectral Density with Feeder Loss: Analog –5.5 dBW/MHz, Digital –20.4 dBW/MHz (35M0M7EDT)
- K factor 4/3
- Gateway Antenna at minimum elevation angle, horizon gain 12.5 dB
- No consideration given for terrain blockage

4. Calculation Results The calculation results showed close agreement with the calculations performed earlier by SkyBridge. The results showed that the greatest interference threat will occur to the Gateway operations when all of these conditions are present; the separation distance between the Gateway site and the FS facility is less than 20 km, the Gateway antennas are at a low elevation angle and the Gateway site is within $\pm 20^0$ of the FS main beam. It appeared that it would be relatively easy to coordinate with respect to these conditions. To verify this finding a coordination run was performed using a fictitious site in the center of the United States. Comsearch's coordination software utilizes the techniques of NBS Technical Note 101. The fictitious location in the center of the United States used for the coordination run was 39^0 00' 00'', 88^0 00' 00". Many iterations of the calculation were made using this location. They included using both the 2.5 and 4.5 meter antenna. For the 2.5-meter antenna the elevation angle was adjusted for 6^0, 45^0, and 90^0 elevation angles. From the coordination runs it became obvious that the worst case interference conditions occurred when the earth station antennas were at their lowest elevation angle, 6^0. For the 4.5-meter antenna only the 6^0-elevation angle was run. The summary sheets of the coordination runs are presented on the following sheets. The results indicated that for this randomly selected site there would be no problem coordinating the SkyBridge Gateway at 11 GHz and no site shielding treatment would be necessary.

The separation distance calculations are presented in graphical format on the pages following the coordination summaries. In general, the calculation results are similar to those results presented by SkyBridge in their previous filings to the FCC but they also have been extended to account for more parametric variation. Mainly, the calculations have been extended to include the various elevation angles of the Gateway antennas, analog and digital modulation and an easily achievable shielding factor of 20 dB. The higher elevation angles of the Gateway antennas produce the lowest interference conditions or the shortest separation distance requirements. Digital modulation by the FS stations produces a reduced interference risk compared to analog to the SkyBridge Gateways. The trend in FS operation in the future is to greater utilization of digital modulation in new systems. Digital system modulations have wider spectral emissions than analog modulations. The wider spectral distribution of digital signals reduces the interference levels at any given frequency.

The calculations are presented in a series of curves that plot separation distance versus off-axis angle of the FS antenna in degrees. There are two plots per figure, with and without shielding. The value of shielding applied was 20 rather than 25 dB used in the SkyBridge calculations. The reason for this value of shielding is because of the findings of the shielding report Comsearch developed for SkyBridge in October 1998 which showed that it would be possible to provide shielding of 20 dB for all the antennas at a Gateway Site.

The data plots presented are:
Gateway Antenna 4.5 meter at an elevation angle of 90^0 and analog modulation.
Gateway Antenna 4.5 meter at an elevation angle of 45^0 and analog modulation.
Gateway antenna 4.5 meter at a minimum elevation angle – 6^0 and analog modulation.
Gateway antenna 4.5 meter at a minimum elevation angle – 6^0 and digital modulation.
Gateway antenna 2.5 meter at a minimum elevation angle – 6^0 and analog modulation.
Gateway antenna 2.5 meter at a minimum elevation angle – 6^0 and digital modulation.

5. Conclusions Based on the calculations and coordination run performed in this task it is concluded that the coordination of the SkyBridge Gateway sites in the United States does not represent a difficult task. To further support this conclusion a plot of the deployment of 11 and 6 GHz FS Links in the United States were also run and are presented in this report. Presently, the 11 GHz Links are rather sparse compared to the 6 GHz Links. Therefore, over the next few years fitting 30 Gateway sites at 11 GHz into the Continental United States should not be a problem. Especially, if the type of desired locations that SkyBridge has described is adhered to, i.e. locations outside RF congested areas, near supporting facilities such as roads, utilities and support activities and near a viable labor force. Also, once the Gateway sites are in place their presence would have little effect on the expansion of FS at 11 GHz. The calculations show that if the main beam of the FS antennas are not aligned or within $\pm 20^0$ of the Gateway sites interference may be avoided. Worst case conditions for coordination occur when the Gateway antennas are at the minimum elevation angle, 6^0, the system modulation is analog and the Gateway site is located within $\pm 20^0$ of the FS main beam. The minimum elevation angle of 6^0 will not occur very often because the design of the system operation will have the hand-offs of the satellites at elevations well above the horizon. Also, the calculated separation distance and coordination results for the 4.5 and 2.5-meter Gateway site antennas are essentially the same because the off-axis characteristics of the antennas are essentially the same.

Separation distance calculations did not take into account local terrain profiling which would further reduce interference signals. Site shielding is a treatment that can be used for interference control for those interference cases that are still present after site selection and other mitigation methods are exhausted. Up to 20 dB of improvement can be realized with shielding for all antennas at a Gateway site.

Siting of future 11 GHz FS systems will not be overly burdened by the presence of the SkyBridge Gateways. Coordination with the Gateway sites will be as straightforward a procedure as the coordination with other 11 GHz FS stations.

Appendix

The following is a list of the publications, Technical Notes, and Reports used in the preparation of this report.

1. National Bureau of standards – Technical Note 101, "Transmission Loss Prediction for Tropospheric Communication Circuits," Volume I, January 1967.

2. Comsearch, "SkyBridge Shielding study Ku-Band," October 1998.

3. Comsearch, Contract INTEL-718, "Interference Prediction and Reduction Techniques for Small Earth Stations," September 1989.

4. FCC Application, "SkyBridge L.C.C. Application to Launch and Operate the SkyBridge Satellite System," 48-SAT—P/LA-97, February 28, 1997.

5. FCC Application Amendment (1), "SkyBridge L.C.C. Application to Launch and Operate the SkyBridge Satellite System," 80-SAT-AMEND-97.

6. FCC Application Amendment (2), SkyBridge L.C.C. Application to launch and Operate the SkyBridge Satellite System, " June 30, 1998.

7. Valkenberg, Van, "Reference Data for Engineers: Radio Electronics, Computer, and Communications – Eighth Edition," Prentice-hall, 1993.

8. International Telecommunication Union, Radio Regulations, "2 Appendices to the Radio Regulations," 1994.

9. International Telecommunication Union, Recommendation ITU-R-SF.1006, "Coordination and Interference Calculations," Section 4/9B, 1993.

SATELLITE EARTH STATION
FREQUENCY COORDINATION DATA
12/18/98

:ompany	ALCATEL	
:arth Station Name, State		SKYBRIDGE, IL
.atitude (DMS)		39 0 0.0 N
.ongitude (DMS)		88 0 0.0 W
;round Elevation AMSL (Ft/m)		750.0 / 228.6
\ntenna Centerline AGL (Ft/m)		10.2 / 3.1
?eceive Antenna Type:	FCC32	FCC Reference 32-25LOG(THETA)
11 GHz Gain (dBi) / Diameter (m)		45.0 / 2.5
3 dB / 15 dB Half Beamwidth		0.44 / 0.88
)perating Mode		RECEIVE ONLY
1odulation		ANALOG
:mission / Receive Band (MHz)		36M0F8W / 10950.0000 - 11200.0000
1ax permissible Interference Power		
11 GHz, 20% (dBW/1 MHz)		-154.3
11 GHz, 0.0100% (dBW/1 MHz)		-143.0
.ow Earth Orbit Satellite		
Azimuth Range (Min/Max) Degrees		0.0 / 360.0
Minimum Elevation Angle Degrees		6.0
?adio Climate		A
?ain Zone		2
1ax Great Circle Coordination Distance (Mi/Km)		
11 GHz		217.5 / 350.0
'recipitation Scatter contour radius (Mi/Km		
11 GHz		1785.2 / 2873.4

Table of Earth Station Coordination Values
12/18/98

Earth Station Name SKYBRIDGE IL
Owner ALCATEL
Latitude 39 0 0.0 N
Longitude 88 0 0.0 W
Ground Elevation (Ft/m) 750.0 / 228.6 AMSL ACL 10.2 Feet AGL
Antenna Model FCC Reference 32-25LOG(THETA)
Objectives: Receive -154.3 (dBW /1 MHz)

Azimuth (Deg)	Horizon Elevation Angle (Deg)	Antenna Disc. Angle (Deg)	11 GHz Antenna Gain (dBi)	Coordination Distance (Km)
0	90.00	89.84	12.50	350.0
5	0.00	86.29	12.50	350.0
10	0.00	81.33	12.50	350.0
15	0.00	76.37	12.50	350.0
20	0.00	71.41	12.50	350.0
25	0.00	66.45	12.50	350.0
30	0.00	61.50	12.50	350.0
35	0.00	56.55	12.50	350.0
40	0.00	51.61	12.50	350.0
45	0.00	46.68	12.50	350.0
50	0.00	41.76	12.50	350.0
55	0.00	36.85	12.50	350.0
60	0.00	31.97	12.50	350.0
65	0.00	27.13	12.50	350.0
70	0.00	22.36	12.50	350.0
75	0.00	17.70	12.50	350.0
80	0.00	13.28	12.50	350.0
85	0.00	9.44	12.50	350.0
90	0.00	7.19	12.50	350.0
95	0.00	8.00	12.50	350.0
100	0.00	11.23	12.50	350.0
105	0.00	15.42	12.50	350.0
110	0.00	19.99	12.50	350.0
115	0.00	24.71	12.50	350.0
120	0.00	29.53	12.50	350.0
125	0.00	34.39	12.50	350.0
130	0.00	39.28	12.50	350.0
135	0.00	44.19	12.50	350.0
140	0.00	49.12	12.50	350.0
145	0.00	54.06	12.50	350.0
150	0.00	59.00	12.50	350.0
155	0.00	63.95	12.50	350.0
160	0.00	68.91	12.50	350.0
165	0.00	73.87	12.50	350.0
170	0.00	78.83	12.50	350.0
175	0.00	83.79	12.50	350.0
180	0.00	88.75	12.50	350.0

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Antenna Model FCC Reference 32-25LOG(THETA)
Objectives: Receive -154.3 (dBW /1 MHz)

Azimuth (Deg)	Horizon Elevation Angle (Deg)	Antenna Disc. Angle (Deg)	11 GHz Antenna Gain (dBi)	Coordination Distance (Km)
185	0.00	93.71	12.50	350.0
190	0.00	98.67	12.50	350.0
195	0.00	103.63	12.50	350.0
200	0.00	108.59	12.50	350.0
205	0.00	113.55	12.50	350.0
210	0.00	118.50	12.50	350.0
215	0.00	123.45	12.50	350.0
220	0.00	128.39	12.50	350.0
225	0.00	133.32	12.50	350.0
230	0.00	138.24	12.50	350.0
235	0.00	143.15	12.50	350.0
240	0.00	148.03	12.50	350.0
245	0.00	152.87	12.50	350.0
250	0.00	157.64	12.50	350.0
255	0.00	162.30	12.50	350.0
260	0.00	166.72	12.50	350.0
265	0.00	170.56	12.50	350.0
270	0.00	172.81	12.50	350.0
275	0.00	172.00	12.50	350.0
280	0.00	168.77	12.50	350.0
285	0.00	164.58	12.50	350.0
290	0.00	160.01	12.50	350.0
295	0.00	155.29	12.50	350.0
300	0.00	150.48	12.50	350.0
305	0.00	145.61	12.50	350.0
310	0.00	140.72	12.50	350.0
315	0.00	135.81	12.50	350.0
320	0.00	130.88	12.50	350.0
325	0.00	125.94	12.50	350.0
330	0.00	121.00	12.50	350.0
335	0.00	116.05	12.50	350.0
340	0.00	111.09	12.50	350.0
345	0.00	106.13	12.50	350.0
350	0.00	101.17	12.50	350.0
355	0.00	96.21	12.50	350.0

Earth Station Preliminary Analysis Report
12/18/98

Earth Station Name SKYBRIDGE IL
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Antenna Model FCC Reference 32-25LOG(THETA)
Objectives: Receive -154.3 (dBW /1 MHz)

	Path				Band (GHz)	Azimuth (Deg)	Dist (Km)	Margin dB	EST OH Loss dB	EST Margin dB
42.	CHANDLER	-	TO	-HENDERSON	11	152.9	121.5	4.1	31.12	-27.0
43.	CHANDLER	-	TO	-HENDERSON	11	152.9	121.5	4.1	31.42	-27.3
44.	HALSTED	-	TO	-ALSIP	11	5.4	311.1	4.1	54.55	-50.5
45.	HAZELRIGG21	*-	TO	-NORTH SALEM*	11	45.2	172.1	3.9	38.60	-34.6
46.	CAIRO	-	TO	-MOUND CITY	11	205.3	244.3	3.9	51.15	-47.2
47.	LOU-B	*-	TO	-LOU-M *	11	112.1	230.0	3.4	46.88	-43.4
48.	SELLERSBURG	-	TO	-FLOYD KNOBS	11	108.5	206.0	3.1	45.61	-42.5
49.	HAMMOND	-	TO	-DYER	11	7.8	293.2	2.7	53.62	-50.9
50.	PADUCAH	-	TO	-METROPOLIS	11	194.1	219.0	2.4	47.54	-45.1
51.	HARVESTER	-	TO	-MARYLAND HTS	11	263.9	225.6	2.4	46.50	-44.1
52.	MINIER	-	TO	-NORMAL	11	326.4	192.6	2.0	42.49	-40.5
53.	STONE	*-	TO	-MORTON *	11	324.7	225.2	1.8	46.04	-44.2
54.	OLIVETTE	-	TO	-ST LOUIS	11	260.8	210.6	1.8	44.86	-43.0
55.	UTICA	-	TO	-NEW ALBANY	11	109.0	216.8	1.7	45.65	-43.9
56.	HANCOCK	*-	TO	-MC COOK QUA*	11	5.6	323.5	1.7	50.59	-48.9
57.	NORWAY	*-	TO	-OTTAWA *	11	348.6	276.4	1.3	51.96	-50.6
58.	MERCHANTS B	-	TO	-MAYWOOD	11	61.2	180.1	1.2	39.20	-37.9
59.	CAIRO	-	TO	-MOUND CITY	11	205.3	244.3	0.9	51.15	-50.2
60.	ATTICA	-	TO	-DANVILLE	11	24.4	156.9	0.8	37.72	-36.8
61.	MINIER	-	TO	-PEORIA	11	326.4	192.6	0.8	40.19	-39.3
62.	OLIVETTE	-	TO	-ST LOUIS	11	260.8	210.6	0.8	44.86	-44.0
63.	ITASCA	-	TO	-VILLA PARK	11	359.6	329.0	0.4	56.03	-55.6
64.	ITASCA	-	TO	-VILLA PARK	11	359.6	329.0	0.4	56.03	-55.6
65.	LAFAYETTE	-	TO	-ATTICA	11	32.1	185.6	0.4	41.86	-41.4
66.	ALSIP	-	TO	-LANSING	11	4.6	296.9	0.3	53.45	-53.1
67.	CRESTWOOD	-	TO	-UTICA	11	107.4	230.6	0.3	46.26	-45.9
68.	ANCHORAGE	-	TO	-WORTHINGTON	11	109.8	231.4	0.1	46.77	-46.6
69.	PLAINFIELD	*-	TO	-NORWAY *	11	356.6	293.4	-0.3	52.33	-52.6
70.	WHITES CRK	-	TO	-JOELTON	11	160.4	317.6	-0.5	54.95	-55.4
71.	OLD NATL BA	-	TO	-HENDERSON	11	161.7	120.1	-0.7	30.41	-31.1
72.	WHEATON	*-	TO	-ROMEOVILLE *	11	358.3	318.1	-0.8	54.56	-55.3
73.	PL35	*-	TO	-PL36 *	11	1.2	316.9	-0.9	55.80	-56.6
74.	PL35	*-	TO	-PL36 *	11	1.2	316.9	-0.9	55.80	-56.6
75.	HOMEWOOD	*-	TO	-PARK FOREST*	11	6.1	286.2	-1.4	53.61	-55.0
76.	JTOWN MTSO	-	TO	-ST MATTHEWS	11	111.6	230.4	-1.6	46.21	-47.7
77.	MAYFIELD	-	TO	-FOLSOMDALE	11	192.8	257.1	-1.7	51.20	-52.8
78.	ST MATTHEWS	-	TO	-UTICA	11	111.1	221.6	-1.7	46.57	-48.2
79.	NORWAY	*-	TO	-PERU *	11	348.6	276.4	-1.9	51.59	-53.4
80.	M1	*-	TO	-PL41 *	11	4.2	296.7	-2.1	54.22	-56.3
81.	M1	*-	TO	-PL41 *	11	4.2	296.7	-2.1	54.22	-56.3
82.	NORWAY	*-	TO	-STREATOR *	11	348.6	276.4	-2.1	51.55	-53.6

Earth Station Preliminary Analysis Report
12/18/98

Earth Station Name SKYBRIDGE IL
Owner
Latitude 39 0 0.0 N
Longitude 88 0 0.0 W
Ground Elevation (Ft/m) 750.0 / 228.6 AMSL ACL 10.2 Feet AGL
Antenna Model FCC Reference 32-25LOG(THETA)
Objectives: Receive -154.3 (dBW /1 MHz)

Path		Band (GHz)	Azimuth (Deg)	Dist (Km)	Margin dB	EST OH Loss dB	EST Margin dB
83.	WA - TO -51ST	11	4.5	322.3	-2.3	56.03	-58.3
84.	MELROSE PK - TO -HALSTED	11	1.6	321.8	-2.7	55.38	-58.1
85.	MELROSE PK - TO -HALSTED	11	1.6	321.8	-2.7	55.38	-58.1
86.	MERCHANTS B - TO -MAYWOOD	11	61.2	180.1	-2.8	39.20	-41.9
87.	CHICAGO CO - TO -S CHICAGO	11	5.4	321.5	-2.9	52.80	-55.6
88.	CHICAGO CO - TO -S CHICAGO	11	5.4	321.5	-2.9	52.80	-55.6
89.	MINIER - TO -PEKIN	11	326.4	192.6	-3.0	42.68	-45.7
90.	NASH-N *- TO -NASH-NXX *	11	160.6	315.3	-3.1	54.17	-57.2
91.	MONMOUTH - TO -BURLINGTON	11	313.8	309.0	-3.1	52.99	-56.1
92.	WATERWORKS *- TO -MTSO II *	11	60.3	179.1	-3.2	40.50	-43.7
93.	WATERWORKS *- TO -MTSO II *	11	60.3	179.1	-3.4	40.49	-43.8
94.	WARDS *- TO -HODGENVILLE*	11	128.5	270.4	-3.4	50.08	-53.4
95.	GRIDLEY - TO -NORMAL	11	340.2	207.3	-3.7	43.61	-47.3
96.	CONCORD - TO -MARRIOTT	11	1.2	322.7	-3.9	55.49	-59.4
97.	BELLEVUE - TO -38TH AVE MT	11	163.2	338.9	-4.3	55.85	-60.1
98.	NORMAL - TO -MINIER	11	332.9	187.0	-4.5	40.72	-45.2
99.	MINIER - TO -LINCOLN	11	326.4	192.6	-4.6	41.74	-46.3
100.	CHICAGO #1 - TO -SPORTS PARK	11	5.4	322.3	-4.8	55.02	-59.8

SATELLITE EARTH STATION
FREQUENCY COORDINATION DATA
12/18/98

Company	ALCATEL	
Earth Station Name, State		SKYBRIDGE, IL
Latitude (DMS)		39 0 0.0 N
Longitude (DMS)		88 0 0.0 W
Ground Elevation AMSL (Ft/m)		750.0 / 228.6
Antenna Centerline AGL (Ft/m)		10.2 / 3.1
Receive Antenna Type:	FCC32	FCC Reference 32-25LOG(THETA)
11 GHz Gain (dBi) / Diameter (m)		45.0 / 2.5
3 dB / 15 dB Half Beamwidth		0.44 / 0.88
Operating Mode		RECEIVE ONLY
Modulation		ANALOG
Emission / Receive Band (MHz)		36M0F8W / 10950.0000 - 11200.0000
Max permissible Interference Power		
11 GHz, 20% (dBW/1 MHz)		-154.3
11 GHz, 0.0100% (dBW/1 MHz)		-143.0
Low Earth Orbit Satellite		
Azimuth Range (Min/Max) Degrees		0.0 / 360.0
Minimum Elevation Angle Degrees		45.0
Radio Climate		A
Rain Zone		2
Max Great Circle Coordination Distance (Mi/Km)		
11 GHz		217.5 / 350.0
Precipitation Scatter contour radius (Mi/Km		
11 GHz		1785.2 / 2873.4

Earth Station Preliminary Analysis Report
12/18/98

Earth Station Name SKYBRIDGE IL
Owner
Latitude 39 0 0.0 N
Longitude 88 0 0.0 W
Ground Elevation (Ft/m) 750.0 / 228.6 AMSL ACL 10.2 Feet AGL
Antenna Model FCC Reference 32-25LOG(THETA)
Objectives: Receive -154.3 (dBW /1 MHz)

Path	Band (GHz)	Azimuth (Deg)	Dist (Km)	Margin dB	EST OH Loss dB	EST Margin dB
1. PITMAN *- TO -WARDS	* 11	128.4	284.1	12.0	51.71	-39.7
2. DALLAS CITY - TO -MACOMB	11	304.9	323.1	0.6	55.77	-55.2
3. GUION ROAD - TO -MIDWEST BLV	11	58.4	178.2	-0.5	40.38	-40.8
4. KEWANEE - TO -GALESBURG	11	327.7	301.3	-4.0	52.07	-56.1
5. PRINCETON *- TO -KEWANEE	* 11	334.1	290.7	-4.6	52.25	-56.8

SATELLITE EARTH STATION
FREQUENCY COORDINATION DATA
12/18/98

:ompany	ALCATEL	
:arth Station Name, State		SKYBRIDGE, IL
.atitude (DMS)		39 0 0.0 N
.ongitude (DMS)		88 0 0.0 W
;round Elevation AMSL (Ft/m)		750.0 / 228.6
\ntenna Centerline AGL (Ft/m)		10.2 / 3.1
;eceive Antenna Type:	FCC32	FCC Reference 32-25LOG(THETA)
11 GHz Gain (dBi) / Diameter (m)		45.0 / 2.5
3 dB / 15 dB Half Beamwidth		0.44 / 0.88
)perating Mode		RECEIVE ONLY
1odulation		ANALOG
:mission / Receive Band (MHz)		36M0F8W / 10950.0000 - 11200.0000
1ax permissible Interference Power		
11 GHz, 20% (dBW/1 MHz)		-154.3
11 GHz, 0.0100% (dBW/1 MHz)		-143.0
.ow Earth Orbit Satellite		
Azimuth Range (Min/Max) Degrees		0.0 / 360.0
Minimum Elevation Angle Degrees		90.0
;adio Climate		A
;ain Zone		2
1ax Great Circle Coordination Distance (Mi/Km)		
11 GHz		217.5 / 350.0
'recipitation Scatter contour radius (Mi/Km		
11 GHz		1785.2 / 2873.4

SATELLITE EARTH STATION
FREQUENCY COORDINATION DATA
12/18/98

:ompany	ALCATEL	
:arth Station Name, State		SKYBRIDGE, IL
.atitude (DMS)		39 0 0.0 N
.ongitude (DMS)		88 0 0.0 W
;round Elevation AMSL (Ft/m)		750.0 / 228.6
\ntenna Centerline AGL (Ft/m)		10.2 / 3.1
₹eceive Antenna Type:	FCC32	FCC Reference 32-25LOG(THETA)
11 GHz Gain (dBi) / Diameter (m)		45.0 / 2.5
3 dB / 15 dB Half Beamwidth		0.44 / 0.88
)perating Mode		RECEIVE ONLY
1odulation		ANALOG
:mission / Receive Band (MHz)		36M0F8W / 10950.0000 - 11200.0000
1ax permissible Interference Power		
11 GHz, 20% (dBW/1 MHz)		-154.3
11 GHz, 0.0100% (dBW/1 MHz)		-143.0
.ow Earth Orbit Satellite		
Azimuth Range (Min/Max) Degrees		0.0 / 360.0
Minimum Elevation Angle Degrees		90.0
₹adio Climate		A
₹ain Zone		2
1ax Great Circle Coordination Distance (Mi/Km)		
11 GHz		217.5 / 350.0
'recipitation Scatter contour radius (Mi/Km		
11 GHz		1785.2 / 2873.4

SATELLITE EARTH STATION
FREQUENCY COORDINATION DATA
12/18/98

Company	ALCATEL	
Earth Station Name, State		SKYBRIDGE, IL
Latitude (DMS)		39 0 0.0 N
Longitude (DMS)		88 0 0.0 W
Ground Elevation AMSL (Ft/m)		750.0 / 228.6
Antenna Centerline AGL (Ft/m)		13.5 / 4.1
Receive Antenna Type:	FCC32	FCC Reference 32-25LOG(THETA)
11 GHz Gain (dBi) / Diameter (m)		51.0 / 4.5
3 dB / 15 dB Half Beamwidth		0.28 / 0.56
Operating Mode		RECEIVE ONLY
Modulation		ANALOG
Emission / Receive Band (MHz)		36M0F8W / 10950.0000 - 11200.0000
Max permissible Interference Power		
11 GHz, 20% (dBW/1 MHz)		-154.3
11 GHz, 0.0100% (dBW/1 MHz)		-143.0
Low Earth Orbit Satellite		
Azimuth Range (Min/Max) Degrees		0.0 / 360.0
Minimum Elevation Angle Degrees		6.0
Radio Climate		A
Rain Zone		2
Max Great Circle Coordination Distance (Mi/Km)		
11 GHz		217.5 / 350.0
Precipitation Scatter contour radius (Mi/Km		
11 GHz		1785.2 / 2873.4

Earth Station Preliminary Analysis Report
12/18/98

Earth Station Name SKYBRIDGE IL
Owner
Latitude 39 0 0.0 N
Longitude 88 0 0.0 W
Ground Elevation (Ft/m) 750.0 / 228.6 AMSL ACL 13.5 Feet AGL
Antenna Model FCC Reference 32-25LOG(THETA)
Objectives: Receive -154.3 (dBW /1 MHz)

	Path	Band (GHz)	Azimuth (Deg)	Dist (Km)	Margin dB	EST OH Loss dB	EST Margin dB
1.	PITMAN *- TO -WARDS *	11	128.4	284.1	33.8	51.46	-17.6
2.	DALLAS CITY - TO -MACOMB	11	304.9	323.1	22.4	55.51	-33.1
3.	GUION ROAD - TO -MIDWEST BLV	11	58.4	178.2	21.3	40.12	-18.7
4.	KEWANEE - TO -GALESBURG	11	327.7	301.3	17.8	51.84	-34.0
5.	PRINCETON *- TO -KEWANEE *	11	334.1	290.7	17.2	52.00	-34.8
6.	ABSHER *- TO -BURDICK *	11	129.2	316.4	16.7	54.22	-37.4
7.	STREATOR - TO -GRIDLEY	11	343.7	248.2	15.8	48.84	-33.0
8.	HODGENVILLE*- TO -ELIZABETHTN*	11	126.9	254.8	15.6	48.52	-32.8
9.	GALESBURG - TO -MONMOUTH	11	318.8	291.7	15.0	50.69	-35.6
10.	GALESBURG - TO -MONMOUTH	11	318.8	291.7	15.0	50.69	-35.6
11.	MONMOUTH - TO -DALLAS CITY	11	313.8	309.0	14.2	52.75	-38.5
12.	KEWANEE - TO -GALESBURG	11	327.7	301.3	13.8	51.45	-37.6
13.	BURDICK *- TO -PITMAN *	11	128.7	299.3	13.6	52.97	-39.4
14.	CASTLETON - TO -GUION ROAD	11	57.5	194.8	12.7	41.81	-29.1
15.	BUCHANAN *- TO -SOUTH BEND *	11	23.5	343.6	11.6	56.10	-44.4
16.	HENDERSON - TO -OLD NATL BA	11	164.4	133.7	11.4	34.68	-23.2
17.	SCHAUMBURG - TO -ITASCA	11	359.2	339.6	10.7	56.63	-45.9
18.	SCHAUMBURG - TO -ITASCA	11	359.2	339.6	10.7	56.63	-45.9
19.	51ST - TO -B1	11	5.6	312.8	10.4	55.04	-44.6
20.	B1 - TO -51ST	11	5.2	297.7	10.4	53.31	-42.9
21.	LINCOLN - TO -SPRINGFIELD	11	317.7	175.9	8.1	39.65	-31.5
22.	OAK PARK *- TO -MCCOOK *	11	3.0	320.8	8.1	55.24	-47.1
23.	GALESBURG - TO -MONMOUTH	11	318.8	291.7	8.0	52.33	-44.2
24.	HENDERSON - TO -CHANDLER	11	161.2	130.9	8.0	32.77	-24.7
25.	HENDERSON - TO -CHANDLER	11	161.2	130.9	8.0	33.07	-25.0
26.	WSNS TV - TO -CHICAGO #1	11	5.3	326.0	7.8	57.08	-49.2
27.	WSNS TV - TO -CHICAGO #1	11	5.3	326.0	7.8	57.08	-49.2
28.	PRINCETON *- TO -KEWANEE *	11	334.1	290.7	7.2	51.08	-43.8
29.	HANCOCK *- TO -HOMEWOOD *	11	5.6	323.5	7.2	50.59	-43.4
30.	METROPOLIS - TO -PADUCAH	11	197.6	214.8	5.7	46.65	-40.9
31.	PEORIA - TO -EAST PEORIA	11	324.6	232.0	5.5	47.84	-42.3
32.	ST MATTHEWS - TO -BREWERY	11	111.1	221.6	5.5	46.12	-40.6
33.	LISLE *- TO -PL-89 *	11	359.2	312.0	5.5	53.86	-48.3
34.	LISLE *- TO -PL-89 *	11	359.2	312.0	5.5	53.86	-48.3
35.	SYRACUSE *- TO -WARSAW *	11	34.6	330.6	5.3	55.20	-49.9
36.	SYRACUSE *- TO -WARSAW *	11	34.6	330.6	5.3	55.53	-50.2
37.	GALESBURG - TO -MONMOUTH	11	318.8	291.7	5.0	52.33	-47.2
38.	GALESBURG - TO -MONMOUTH	11	318.8	291.7	5.0	52.33	-47.2
39.	OAK PARK *- TO -HOMEWOOD *	11	3.0	320.8	5.0	55.24	-50.2
40.	MTSO - TO -HALSTED	11	5.6	319.4	4.9	55.44	-50.5
41.	MTSO - TO -HALSTED	11	5.6	319.4	4.9	55.44	-50.5

Earth Station Preliminary Analysis Report
12/18/98

Earth Station Name SKYBRIDGE IL
Owner
Latitude 39 0 0.0 N
Longitude 88 0 0.0 W
Ground Elevation (Ft/m) 750.0 / 228.6 AMSL ACL 13.5 Feet AGL
Antenna Model FCC Reference 32-25LOG(THETA)
Objectives: Receive -154.3 (dBW /1 MHz)

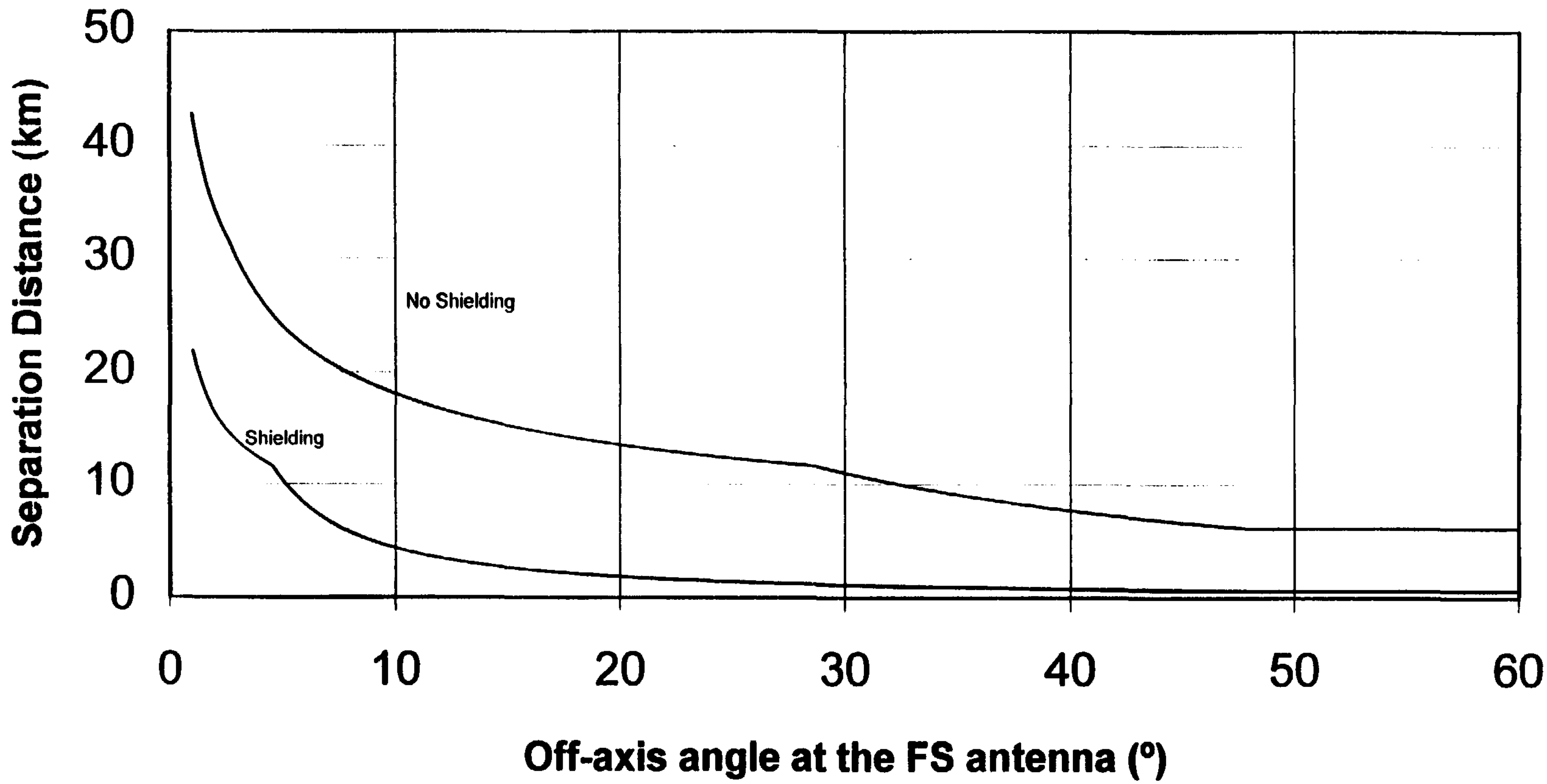
Path				Band (GHz)	Azimuth (Deg)	Dist (Km)	Margin dB	EST OH Loss dB	EST Margin dB
42.	CHANDLER	- TO -	HENDERSON	11	152.9	121.5	4.1	30.85	-26.7
43.	CHANDLER	- TO -	HENDERSON	11	152.9	121.5	4.1	31.15	-27.0
44.	HALSTED	- TO -	ALSIP	11	5.4	311.1	4.1	54.30	-50.2
45.	HAZELRIGG21*	- TO -	NORTH SALEM*	11	45.2	172.1	3.9	38.36	-34.4
46.	CAIRO	- TO -	MOUND CITY	11	205.3	244.3	3.9	50.85	-46.9
47.	LOU-B *	- TO -	LOU-M *	11	112.1	230.0	3.4	46.62	-43.2
48.	SELLERSBURG	- TO -	FLOYD KNOBS	11	108.5	206.0	3.1	45.33	-42.2
49.	HAMMOND	- TO -	DYER	11	7.8	293.2	2.7	53.36	-50.6
50.	PADUCAH	- TO -	METROPOLIS	11	194.1	219.0	2.4	47.26	-44.8
51.	HARVESTER	- TO -	MARYLAND HTS	11	263.9	225.6	2.4	46.24	-43.8
52.	MINIER	- TO -	NORMAL	11	326.4	192.6	2.0	42.24	-40.2
53.	STONE *	- TO -	MORTON *	11	324.7	225.2	1.8	45.79	-43.9
54.	OLIVETTE	- TO -	ST LOUIS	11	260.8	210.6	1.8	44.60	-42.7
55.	UTICA	- TO -	NEW ALBANY	11	109.0	216.8	1.7	45.40	-43.6
56.	HANCOCK *	- TO -	MC COOK QUA*	11	5.6	323.5	1.7	50.59	-48.9
57.	NORWAY *	- TO -	OTTAWA *	11	348.6	276.4	1.3	51.70	-50.3
58.	MERCHANTS B	- TO -	MAYWOOD	11	61.2	180.1	1.2	38.96	-37.7
59.	CAIRO	- TO -	MOUND CITY	11	205.3	244.3	0.9	50.85	-49.9
60.	ATTICA	- TO -	DANVILLE	11	24.4	156.9	0.8	37.45	-36.6
61.	MINIER	- TO -	PEORIA	11	326.4	192.6	0.8	39.97	-39.1
62.	OLIVETTE	- TO -	ST LOUIS	11	260.8	210.6	0.8	44.60	-43.7
63.	ITASCA	- TO -	VILLA PARK	11	359.6	329.0	0.4	55.78	-55.3
64.	ITASCA	- TO -	VILLA PARK	11	359.6	329.0	0.4	55.78	-55.3
65.	LAFAYETTE	- TO -	ATTICA	11	32.1	185.6	0.4	41.60	-41.2
66.	ALSIP	- TO -	LANSING	11	4.6	296.9	0.3	53.20	-52.9
67.	CRESTWOOD	- TO -	UTICA	11	107.4	230.6	0.3	46.01	-45.7
68.	ANCHORAGE	- TO -	WORTHINGTON	11	109.8	231.4	0.1	46.52	-46.3
69.	PLAINFIELD *	- TO -	NORWAY *	11	356.6	293.4	-0.3	52.08	-52.3
70.	WHITES CRK	- TO -	JOELTON	11	160.4	317.6	-0.5	54.70	-55.2
71.	OLD NATL BA	- TO -	HENDERSON	11	161.7	120.1	-0.7	30.15	-30.8
72.	WHEATON *	- TO -	ROMEOVILLE *	11	358.3	318.1	-0.8	54.32	-55.1
73.	PL35 *	- TO -	PL36 *	11	1.2	316.9	-0.9	55.54	-56.3
74.	PL35 *	- TO -	PL36 *	11	1.2	316.9	-0.9	55.54	-56.3
75.	HOMEWOOD *	- TO -	PARK FOREST*	11	6.1	286.2	-1.4	53.34	-54.7
76.	JTOWN MTSO	- TO -	ST MATTHEWS	11	111.6	230.4	-1.6	45.96	-47.5
77.	MAYFIELD	- TO -	FOLSOMDALE	11	192.8	257.1	-1.7	50.93	-52.5
78.	ST MATTHEWS	- TO -	UTICA	11	111.1	221.6	-1.7	46.31	-47.9
79.	NORWAY *	- TO -	PERU *	11	348.6	276.4	-1.9	51.34	-53.2
80.	M1 *	- TO -	PL41 *	11	4.2	296.7	-2.1	53.95	-56.0
81.	M1 *	- TO -	PL41 *	11	4.2	296.7	-2.1	53.95	-56.0
82.	NORWAY *	- TO -	STREATOR *	11	348.6	276.4	-2.1	51.30	-53.4

Earth Station Preliminary Analysis Report
12/18/98

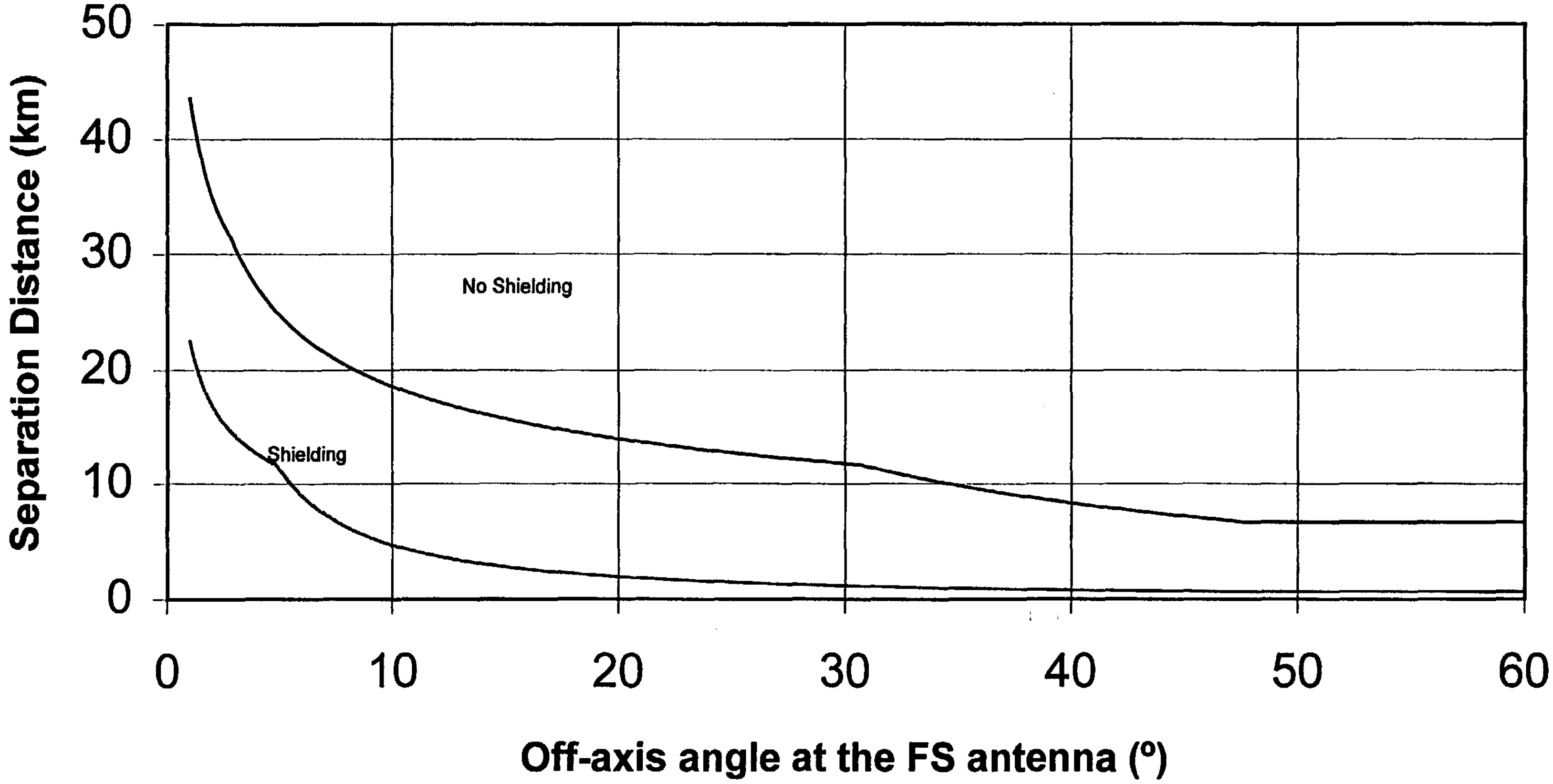
Earth Station Name SKYBRIDGE IL
Owner
Latitude 39 0 0.0 N
Longitude 88 0 0.0 W
Ground Elevation (Ft/m) 750.0 / 228.6 AMSL ACL 13.5 Feet AGL
Antenna Model FCC Reference 32-25LOG(THETA)
Objectives: Receive -154.3 (dBW /1 MHz)

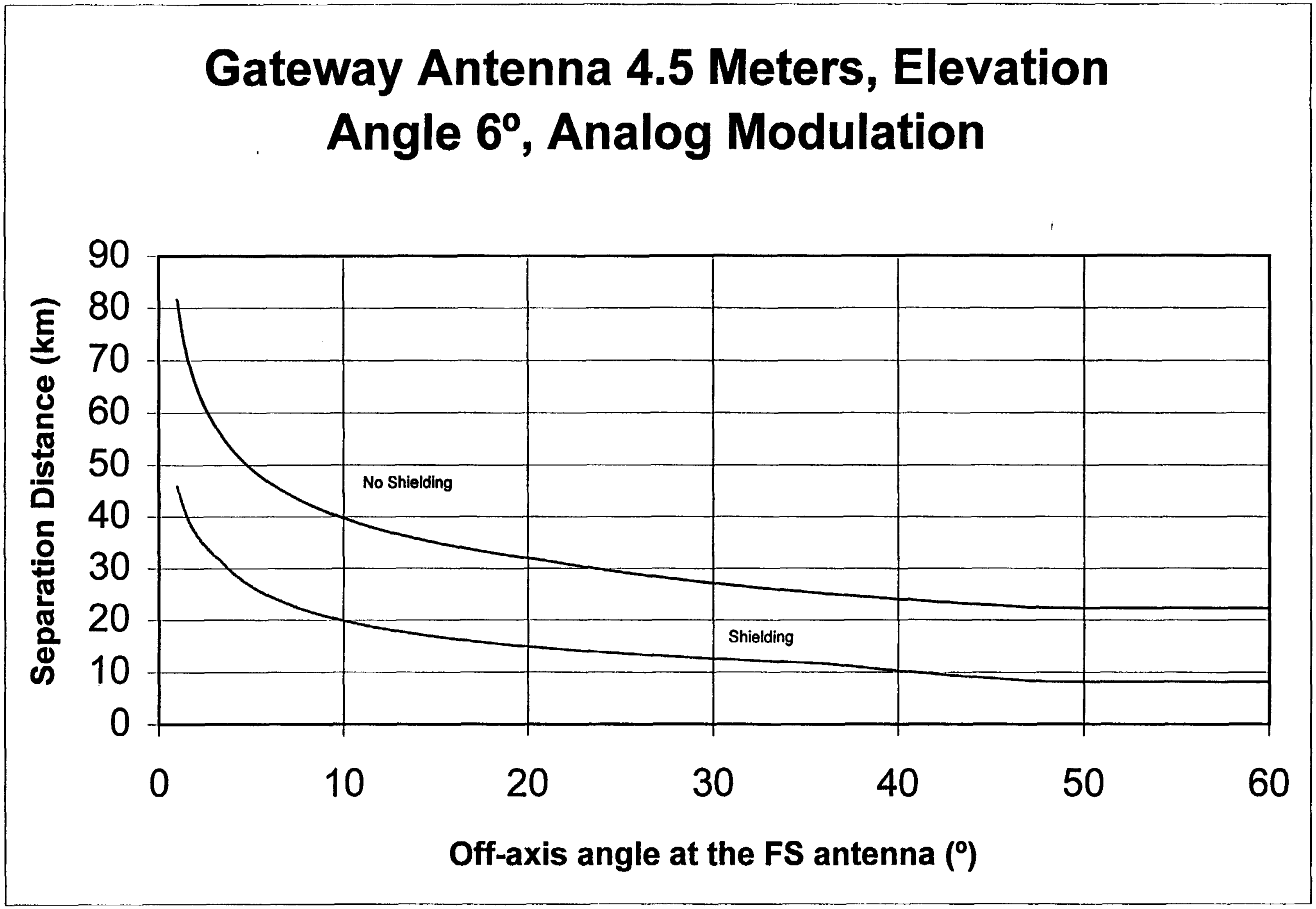
	Path			Band (GHz)	Azimuth (Deg)	Dist (Km)	Margin dB	EST OH Loss dB	EST Margin dB
83.	WA	- TO	-51ST	11	4.5	322.3	-2.3	55.77	-58.1
84.	MELROSE PK	- TO	-HALSTED	11	1.6	321.8	-2.7	55.12	-57.8
85.	MELROSE PK	- TO	-HALSTED	11	1.6	321.8	-2.7	55.12	-57.8
86.	MERCHANTS B	- TO	-MAYWOOD	11	61.2	180.1	-2.8	38.96	-41.7
87.	CHICAGO CO	- TO	-S CHICAGO	11	5.4	321.5	-2.9	52.59	-55.4
88.	CHICAGO CO	- TO	-S CHICAGO	11	5.4	321.5	-2.9	52.59	-55.4
89.	MINIER	- TO	-PEKIN	11	326.4	192.6	-3.0	42.42	-45.4
90.	NASH-N	*- TO	-NASH-NXX *	11	160.6	315.3	-3.1	53.93	-57.0
91.	MONMOUTH	- TO	-BURLINGTON	11	313.8	309.0	-3.1	52.76	-55.9
92.	WATERWORKS	*- TO	-MTSO II *	11	60.3	179.1	-3.2	40.24	-43.4
93.	WATERWORKS	*- TO	-MTSO II *	11	60.3	179.1	-3.4	40.24	-43.6
94.	WARDS	*- TO	-HODGENVILLE*	11	128.5	270.4	-3.4	49.84	-53.2
95.	GRIDLEY	- TO	-NORMAL	11	340.2	207.3	-3.7	43.37	-47.0
96.	CONCORD	- TO	-MARRIOTT	11	1.2	322.7	-3.9	55.23	-59.1
97.	BELLEVUE	- TO	-38TH AVE MT	11	163.2	338.9	-4.3	55.61	-59.8
98.	NORMAL	- TO	-MINIER	11	332.9	187.0	-4.5	40.48	-45.0
99.	MINIER	- TO	-LINCOLN	11	326.4	192.6	-4.6	41.49	-46.1
100.	CHICAGO #1	- TO	-SPORTS PARK	11	5.4	322.3	-4.8	54.78	-59.5

Gateway Antenna 4.5 Meters, Elevation Angle 90°, Analog Modulation

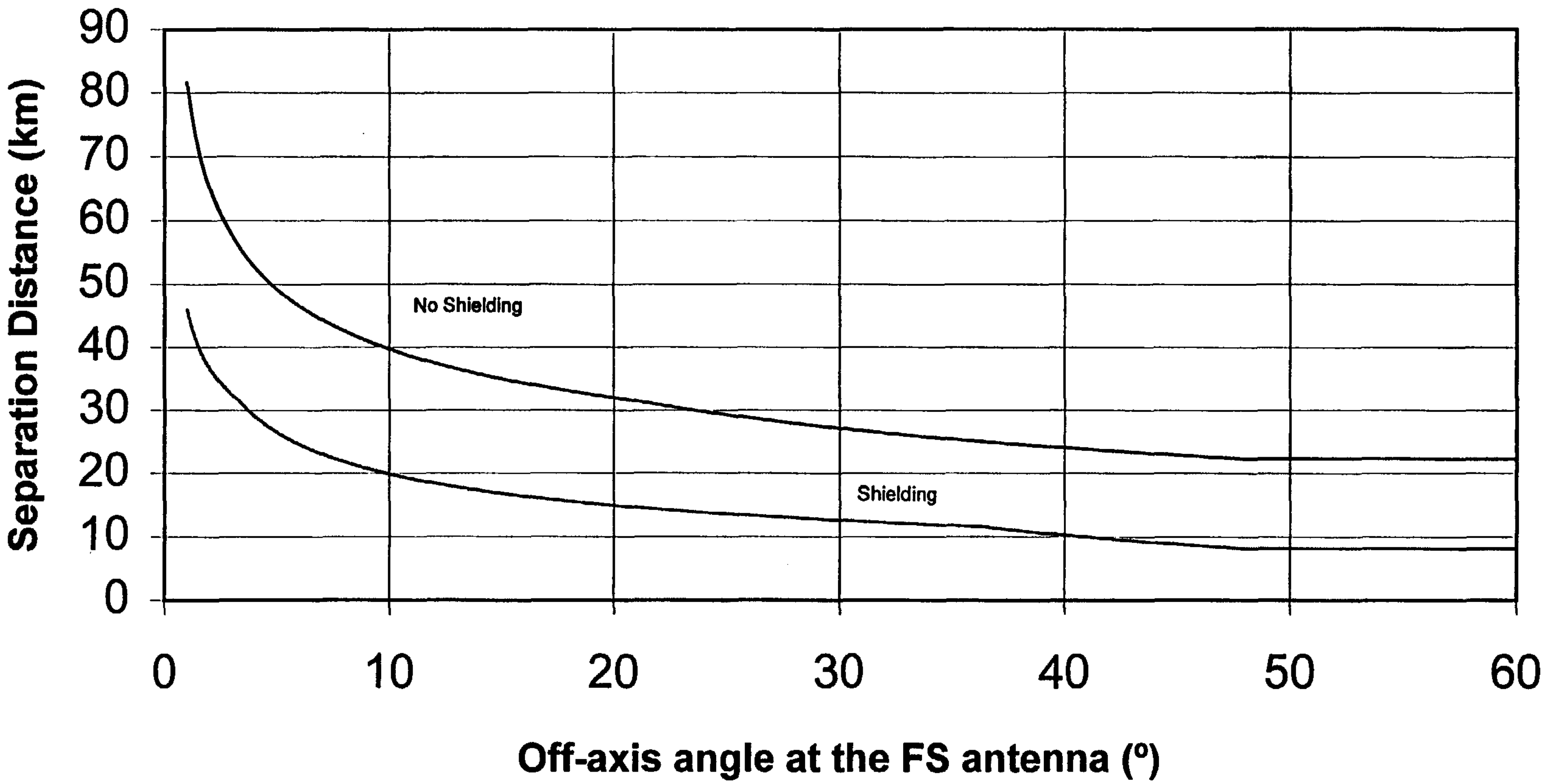


Gateway Antenna 4.5 Meters, Elevation Angle 45º, Analog Modulation

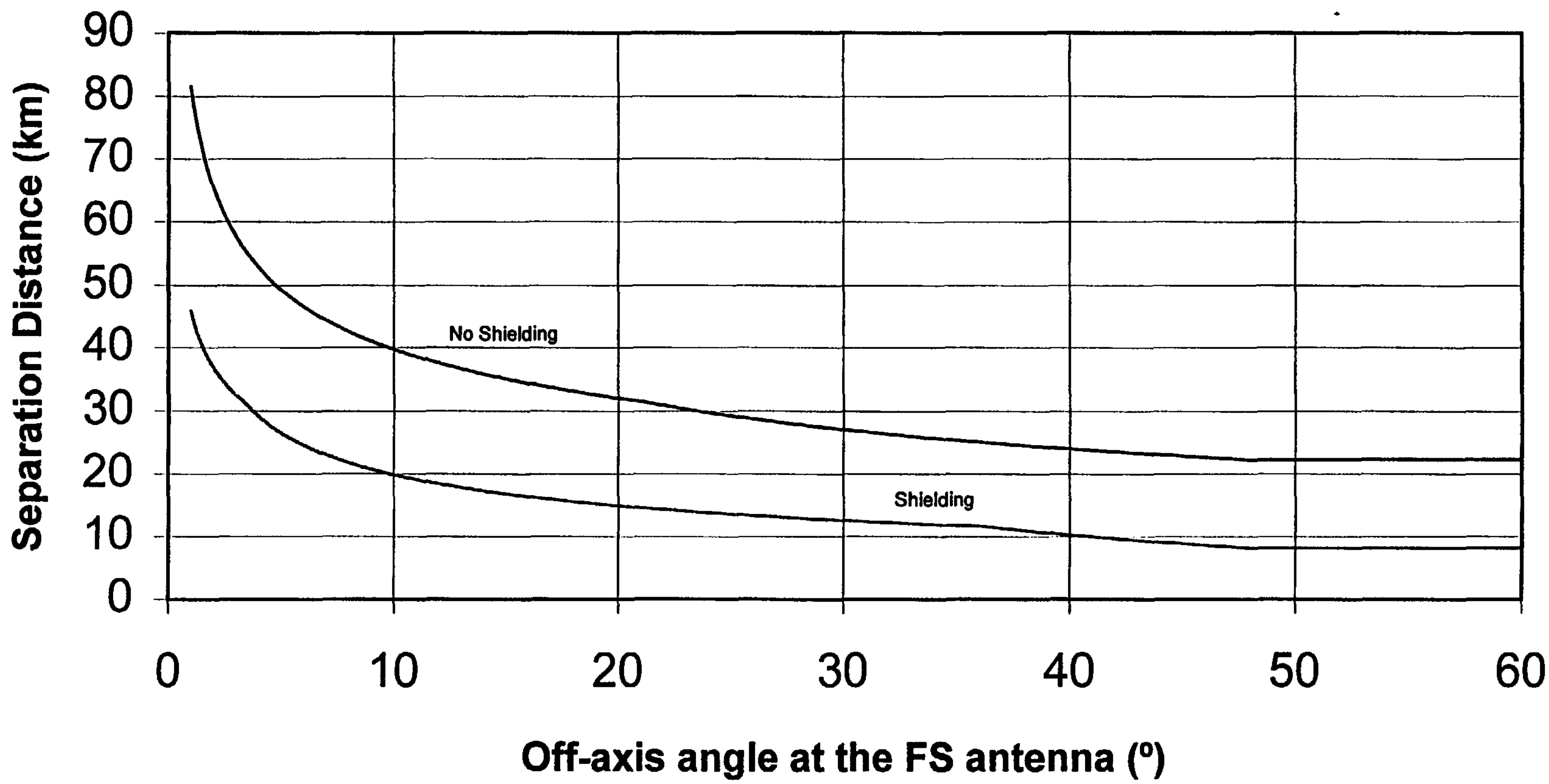


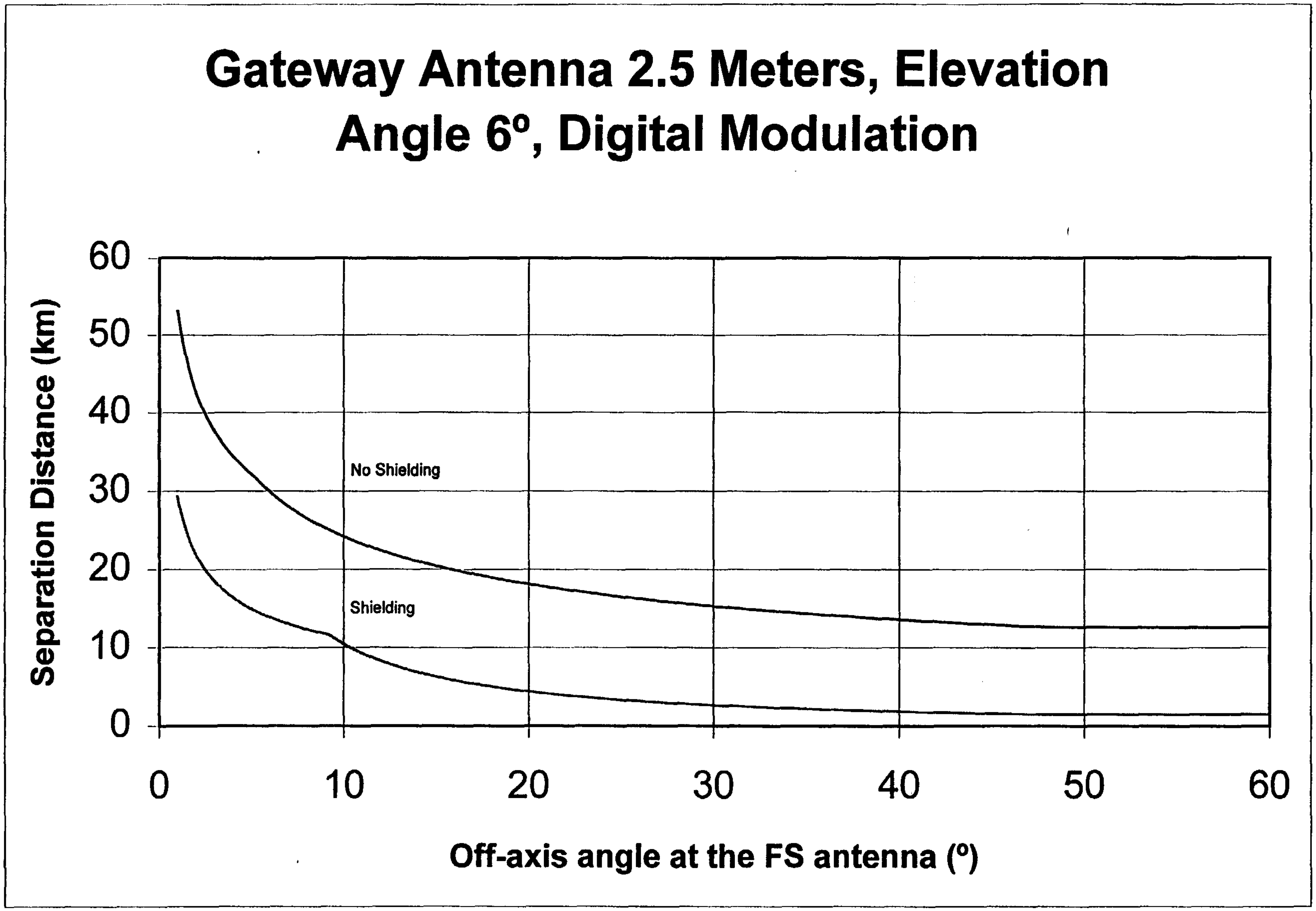

Gateway Antenna 4.5 Meters, Elevation Angle 6º, Analog Modulation
Separation Distance (km)
0
10
20
30
40
50
60
70
80
90
Off-axis angle at the FS antenna (º)
0
10
20
30
40
50
60
No Shielding
Shielding

Gateway Antenna 4.5 Meters, Elevation Angle 6º, Analog Modulation



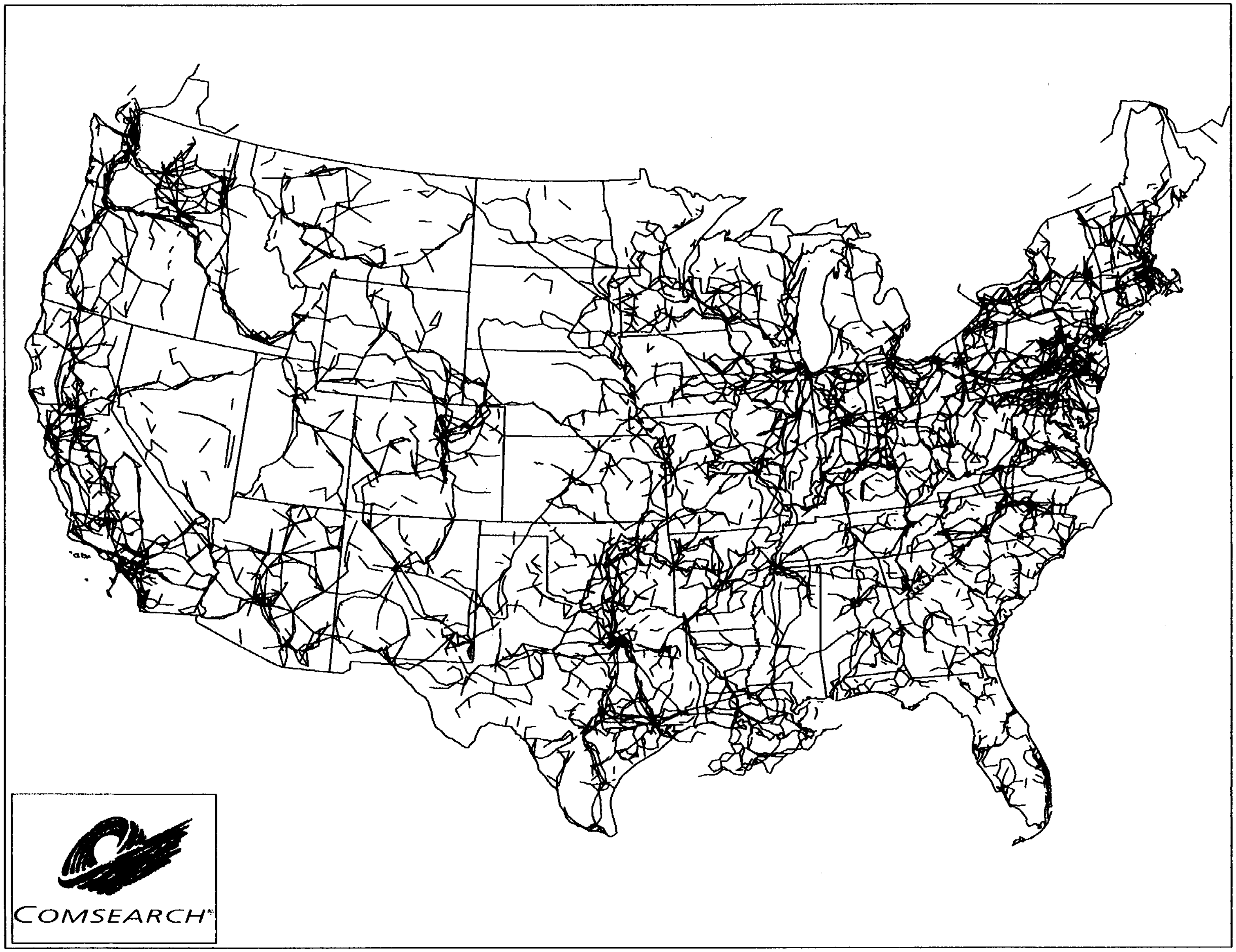
Gateway Antenna 2.5 Meters, Elevation Angle 6º, Analog Modulation




Gateway Antenna 2.5 Meters, Elevation Angle 6°, Digital Modulation
Separation Distance (km)
0
10
20
30
40
50
60
No Shielding
Shielding
Off-axis angle at the FS antenna (°)

11.0 GHz Terrestrial Microwave Paths in the United States

6.0 GHz Terrestrial Microwave Paths in the United States



D

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APPENDIX D

SkyBridge Shielding Study
Ku-Band

February 19, 1999

prepared by

COMSEARCH

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0. Executive Summary

Shielding for the SkyBridge Gateway sites is a viable method for facilitating the coordination process with terrestrial microwave systems that share the same 11-GHz frequency band. There are unique shielding issues that must be addressed for the SkyBridge earth stations and these are directly the result of the antenna systems operating with non-geostationary satellites that must be viewable at all azimuths down to an elevation of 6°. The SkyBridge frequency range poses less of a design problem than the requirement of tracking antennas at the Gateway sites, although most past shielding work has been performed at C-Band.

Initial site selection for the Gateway sites should be made after a comprehensive interference analysis of the potential site area has been performed and indicates benign interference to, or from, the site. If any suspicion is raised in the analysis with regard to interference conditions and the site is still under consideration, site measurements should be performed before the site is acquired. The site measurements will quantify the interference conditions for the site and establish shielding requirements. In no case should a site be acquired that is in the direct path of an 11-GHz terrestrial microwave link.

This study shows that the SkyBridge Gateway Sites can be constructed with shielding using technology and construction methods that are well established and have been successful in the past. The site shielding is a function of the relative geometry of the shield and the antennas at the site and the relative azimuth of the interference source and/or victim. Knife-edge diffraction, over and around the shield, and reflections into the site from tall structures in the vicinity of the site, or reflections within the site due to diffraction from the shield are the main ways a shield can be compromised. These limiting conditions can be dealt with effectively by proper initial site selection, the correct design of the shield and the site, and the vigilance and action needed to prevent the addition of structures near the Gateway site that could cause reflections.

Site shielding can be augmented by natural and man-made structures in the vicinity of the Gateway. The net effect of site and natural shielding in the area is additive. Therefore, if a site has 20 dB of constructed shielding and surrounding hills and trees provide 15 dB of shielding, the site will have a net shielding of 35 dB.

The installation of the shielding must be performed properly so that it will provide the expected results. The shield must be constructed of the correct materials; the positioning of the shield structure and the antennas must be planned so that the minimum elevation angles can be obtained. Grounding of the shield must be performed at each support member and the grounding should be tied into the overall site ground system. Shielding effectiveness measurements should be performed immediately after installation.

Maintenance of the shield structure should be minimal. Inspections should be conducted periodically to insure that weathering or corrosion has not compromised the materials. Aesthetic treatments should also be inspected at these times. If deterioration is observed the materials should be restored in the most effective manner possible. If compromise of the shielding is suspected a shielding expert should be called in to examine the structure.

1. Introduction

On August 3, 1998, an engineering task to evaluate the effectiveness of earth station shielding in the 11-GHz common-carrier band was assigned to COMSEARCH by SkyBridge Inc. The shielding study was commissioned by SkyBridge to produce information that will be used in the development, design and construction of their earth station gateway facilities. The site shielding will facilitate the earth station coordination process and ensure long-term spectrum sharing with existing and future point-to-point microwave facilities.

In this study, COMSEARCH examined existing shielding techniques and their effectiveness, principally in the 11-GHz band. This band is the receive frequency band for the SkyBridge earth station network, and it is shared with fixed point-to-point microwave services. The study focused on effective methods to shield the SkyBridge earth station facility configurations and their operation with the 80-satellite non-geostationary (NGSO) constellation. The antenna sizes and number for the two main facility configurations were key elements in the evaluation of site performance and shielding effectiveness. Additionally, the factors of initial cost, life-cycle maintenance cost, technical complexity, bandwidth limitations, market availability, and aesthetics were taken into account in the evaluation. Methods that could be used in conjunction with shielding to enhance the isolation of the gateway antennas from terrestrial microwave signals were also examined. These methods included site selection (physical layout and natural shielding), earth station antenna design and operational work around.

Based on interference analyses performed by SkyBridge and reviewed by COMSEARCH, shielding that would provide 20 dB or more of isolation for each operational antenna at a Gateway site would help to ensure that the system would meet both long- and short-term interference objectives. To obtain this isolation, the shielding would have to be installed in such a way as to isolate Gateway antennas from signals originating at terrestrial stations located at any relative azimuth to the Gateway antennas. The minimum discrimination angle for the Gateway antennas to the terrestrial antennas will be 6°.

The information obtained in this study was derived from a comprehensive shielding literature search, past shielding measurement work, theoretical and industrial electromagnetic compatibility focus group studies, interviews and discussions with practitioners in the electromagnetic shielding field (product vendors, architects, and construction engineers) and operations personnel who work at sites with shielding treatments in place. A complete listing of the sources used is included in Appendix A of this report.

2. SkyBridge Shielding Issues

The Gateway antennas must have full range of motion and a clear sky view at a minimum elevation angle of +6° at all azimuths. Because of the elevation clearance requirement which allows for main beam clearance, all of the Gateway antennas must be separated from each other by a minimum distance. The antenna separation distance for those Gateway sites with 4.5-meter antennas is 42.6 meters, while the distance for those with 2.5-meter antennas is 23.8 meters. These separation distances assume that all of the antennas are the same, that their motion is symmetrical around a single pivot point and that their base positions are at the same level.

To effectively shield an antenna, the shield structure should at least be as tall as the antenna when it is at a zero degree elevation. A taller structure yields a more effective shield; however, the shield would need to be further separated from the antenna. The required separation distance to structures and buildings from the antennas is a function of the antenna height at its lowest operating elevation and the vertical heights of all structures. All obstacle positions must allow the cylindrical beam formed by the antenna to clear the structure or building. The main consideration in this instance is obstacle clearance of the side of the cylinder formed by the bottom lip of the antenna. Therefore, higher shielding walls lead to larger sites. This will have a direct cost impact for the additional site dimensions and shield size. The wall shielding for the Gateway sites with the 4.5-meter antennas should have a minimum height of 6.3 meters. The wall shielding for the Gateway sites with the 2.5-meter antennas should have a minimum height of 4.3 meters. These minimum wall heights are a function of the antenna size, minimum antenna elevation angle and the height of the bottom antenna lip above the ground. SkyBridge personnel reported the latter height to be 1.8 meters. For the shielding height of 6.3 meters, the separation distance for 6° clearance of the 4.5-meter antennas will be 42.6 meters. For the shielding height of 4.3 meters, the separation distance for 6° clearance of the 2.5-meter antennas will be 23.8 meters. The optimum height of the shielding will be determined from the analysis of theoretical and empirical data examined in this study, tradeoffs with respect to the antenna operations at the site and the overall costs associated with the site area and construction of the shield. The shielding height which will be determined will influence the heights of the other buildings and structures at the Gateway site.

Two Gateway site configurations are being considered: one for high-traffic areas and another for low- to moderate-traffic areas. The high-traffic site will consist of six 4.5-meter antennas. Five will be operational and the sixth will be a standby. The other configuration will have three 2.5-meter antennas, all of which will be operational. In addition to the antennas, the site will contain equipment and operations building, utility support appliances and structures, emergency power generators and personnel parking.

3. Earth Station Shielding

Several types of shields can be used to electromagnetically isolate earth station facilities such as the SkyBridge Gateway sites in order to prevent them from generating or receiving interference. Shields may be described by their material and geometry. Shielding can take the form of walls or panels, pits or earthen berm. The shields can be designed for the specific purpose of reducing signals to and from the site, or they can simply be the fortuitous location of a building, structure and/or natural terrain feature that provides ample shielding. The engineering literature on shielding has a large number of examples of shielding to earth stations created by man-made and natural shields that provide up to 15 dB of shielding. The SkyBridge Gateway sites can also benefit by this type of shielding; however, since the requirement of shielding for these sites is 20 dB or greater and this criterion must be capable of being applied to multiple antenna azimuths, a comprehensive design of shielding for the sites is required.

3.1 Types of Shields

Metal shields are commonly used for shielding earth station sites. They can either be of solid or open construction. Solid metal shields provide the greatest reflectivity and opaqueness across the electromagnetic spectrum. Open construction such as screen material, meshes or perforated material will have attenuation versus frequency response that will be a function of the material openings. The characteristics of an open construction shield will approach those of a solid shield, as the material openings are much smaller than the wavelength of the signal frequency being shielded. Open construction is generally cheaper and easier to work with, and it provides less wind resistance than solid shields. Two operational disadvantages of metal shields are their high reflectivity and the reflections they generate. Reflections can create unexpected interference problems to other facilities or even back into the facility being protected. A maintenance disadvantage of metallic shielding is the lifelong protection required preventing rust and oxidation. The aesthetic concerns of metal shields pose another factor. Even under well-maintained conditions, a metal (solid or open) may still be an eyesore.

Masonry walls have also been used as shielding for earth stations. They are not as common as metallic shields, but if properly designed with the requisite dimensions of thickness, height and construction material, they can be used to both absorb and reflect electromagnetic fields and thus be an effective shield.

Pit shielding and earthen berm utilize the characteristics of the soil and reinforcing material around the pit or berm for shielding. The pit is a relatively deep hole in the ground. The shielding effectiveness of a pit is uniquely dependent on its geometry and depth. Properly designed pits have produced shielding in excess of 40 dB for earth station antennas. A berm is usually formed by earth-fill dirt to form a barrier that acts as a shield. The berm is characterized by its height, width across the top and downward slope. Expected shielding effectiveness of a berm is usually in the range of 15 to 20 dB. Berms are usually applied to interference to or from one direction and in conjunction with another method of shielding.

The main advantage of pit shielding is the high shielding factor it provides. Its disadvantages include the space it occupies the fact that it is more applicable to geostationary satellite terminals rather than non-geostationary ones and its high installation cost as measured in space requirements and labor to install. Berm shielding is relatively inexpensive since the fill dirt will come directly from the local site construction. However, its effectiveness is usually only in one direction, and the shielding effectiveness is therefore only moderate. Because of these disadvantages, pits and berms will not be the shielding methods recommended for the SkyBridge Gateway sites.

Non-standard methods of shielding that are discussed in this study involve utilizing new types of earth station antennas. One type of new antenna would be supplied with a shield around it with an opening for its aperture. The shield would be similar to a radome, but it would be constructed of microwave absorbing material. All of the antenna surfaces with the exception of the antenna's effective aperture would be shielded. The entire radome and antenna would rotate in place. This would keep the antenna aperture aimed at the satellite while the remainder of the antenna surfaces would be shielded no matter where the antenna was aimed. The second type of earth station antenna would be an electronically steerable conformal array. These antennas can be flat plates installed close to ground level. The physical spacing of antennas of this type is reduced since physical clearance of adjacent antennas is no longer an issue. These antennas can be shielded individually or by overall site shielding. The disadvantage of pursuing the first approach is that this type of antenna has never been built. Additionally, although the second type has been used in military applications at lower microwave frequencies, it has never been built for 11-GHz commercial applications. Since no commercial antenna manufacturers build either of these antennas, it is anticipated that the engineering costs in developing these antennas would be considerable.

3.2 Combination of Shielding Methods

Combining methods of shielding for the earth station sites will probably produce the most technically efficient and cost-effective approach. An example would be an approach that utilizes a concrete wall sitting on a berm constructed from the fill dirt obtained during the site construction. The wall would consist of concrete panels that sandwich a metallic mesh material between them. The outside of the wall will have a nylon matrix of material installed that will be used to support locally viable vines which will be planted to grow to the top of the wall. This will produce an aesthetically attractive site that will technically combine electromagnetic absorption and reflection to provide the shielding required for the site. Electromagnetic absorption and diffusion will result from the use of the vines and concrete panels in the wall, while reflection will result from the use of the concrete and metallic mesh material. The net result will be interference signal reduction within the earth station site by using a shield that utilizes the mechanisms of signal absorption, diffusion and reflection.

3.3 Site Configurations

Figures 1.A through 1.E are sketches for some of the possible antenna arrangements at the six-antenna Gateway sites. The antenna configuration selected will affect the shielding to each of the antennas because the net shielding to an antenna is a function of its position behind the shield, the azimuth of the interference signal relative to the shield and each of the antennas and any reflections created within the shielded area. The separation distances between the antennas and the antennas and the shield are a function of the antenna size, the lowest operational elevation angle for the antennas and the height of the shield.

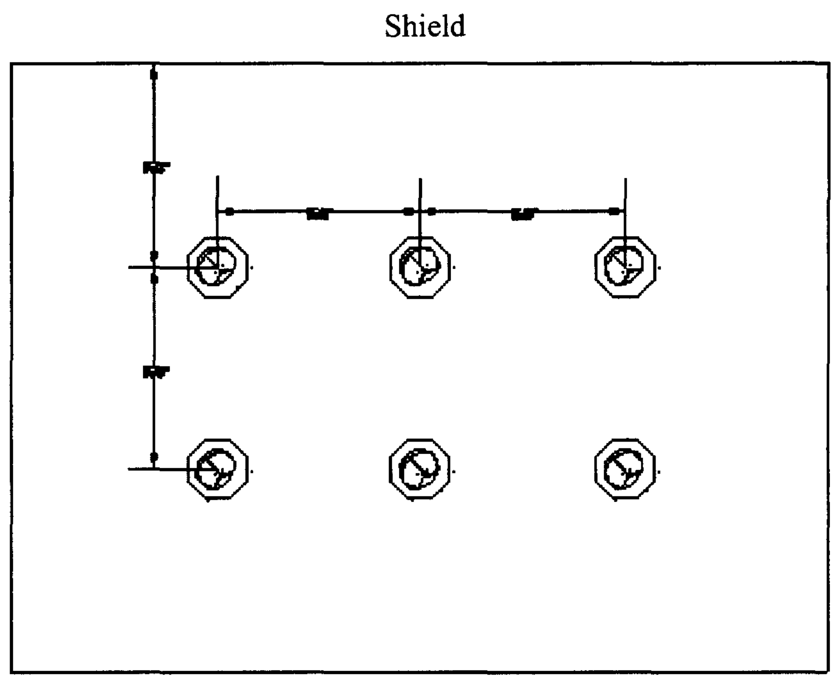


Figure 1.A – Rectangular Site Configuration, Enclosed

Shield

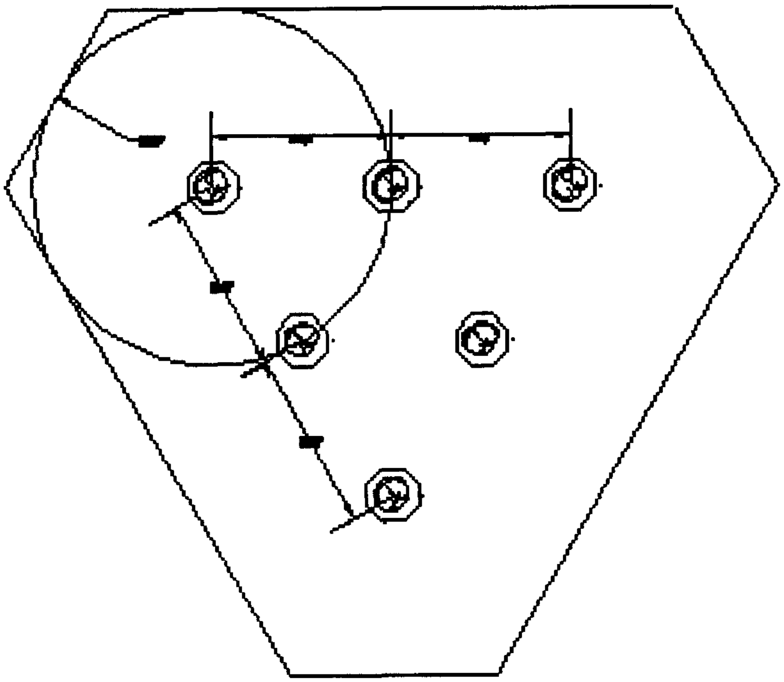


Figure 1.B – Triangular Site Configuration, Enclosed

Shield

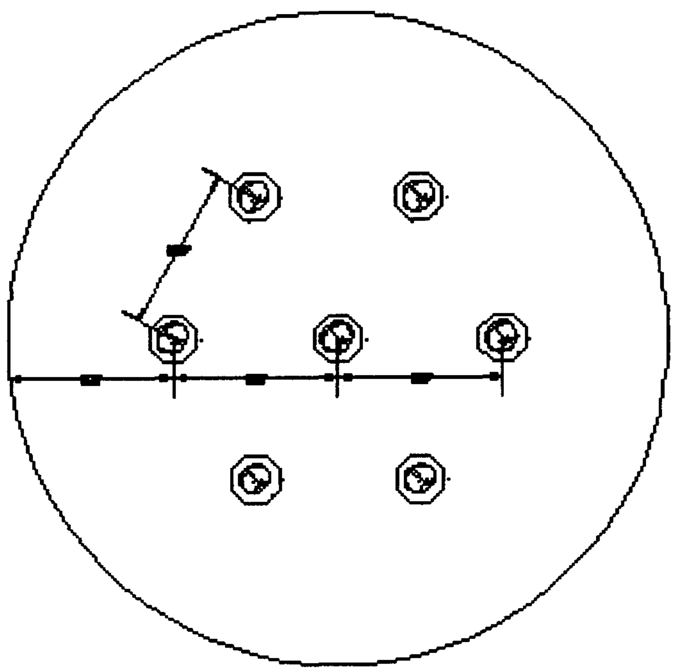


Figure 1.C – Circular Site Configuration, Enclosed

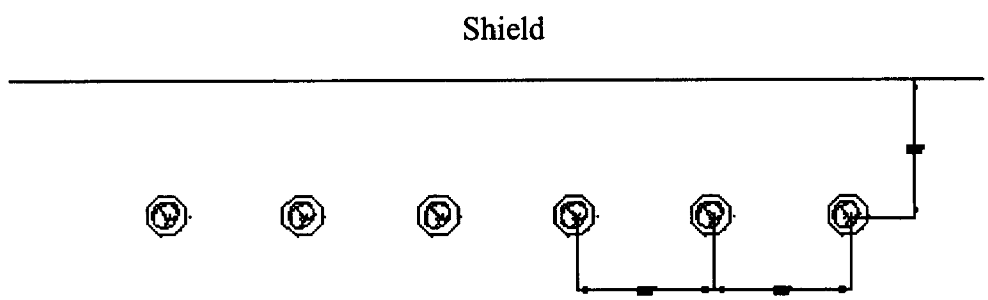


Figure 1.D – Linear Site Configuration

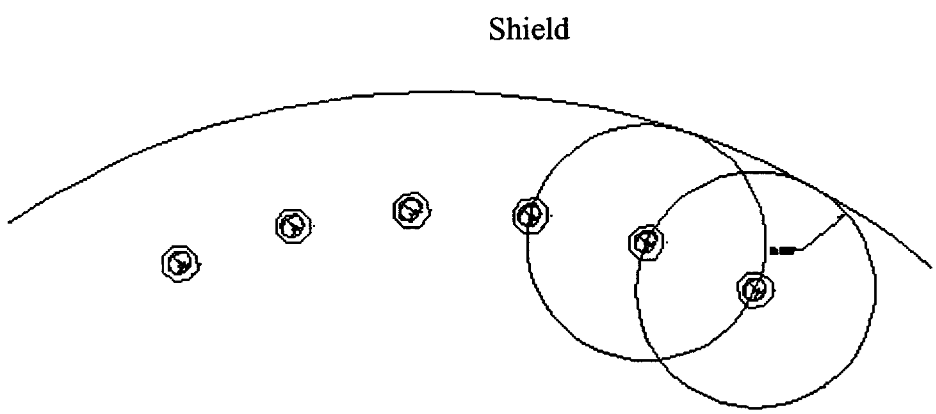


Figure 1.E – Arc Site Configuration

3.4 RF Transmittance of Shielding Material

Solid metal shields are opaque to RF signals. Metal can be used effectively as a component in the design of a shielding structure. Building materials that consist of metal such as siding and roofing panels made of corrugated aluminum or steel are well suited for the construction of a RF shield. The shield must be designed with no openings and effective electrical joining or overlap of the panels of the structure should be part of the design. The limitations of shielding effectiveness occur over the top or around the sides of the shield through the propagation mechanism of diffraction. However, in this section we will deal with the transmittance characteristics of the shield to show how effective various materials are in attenuating RF signals.

The RF attenuation through a material can be predicted if the conductivity and permeability values of the material are known. The relationship of these values are given in the following formula which calculates the penetration depth of the material where the RF signal Voltage is reduced to 37% of its surface value.

$$D = \sqrt{\frac{1}{\pi f q x}}$$

Where,

D	=	penetration depth into material of 37%, meters (20log0.37 = 8.64 dB)
f	=	RF frequency, Hz
q	=	permeability of material, Henrys/meter (1.257×10^{-6} for non-magnetic material)
x	=	conductivity of material, mho/meter (equivalent to $(\text{ohm-meter})^{-1}$).

Using this formula, the attenuation of various materials may be predicted by determining the number of penetration depth increments that comprise the thickness of the shield. Interestingly, the phase of the signal penetrating the shield may also be calculated, since each depth increment retards the phase of the signal 1 radian, or 57.3°. However, this phase shift is not of interest here as it does not add any information to the overall reduction in transmittance of the RF signal through the material.

To determine the attenuation of a one-inch thickness of the shield material, the following formula was used.

$$A = 39.37\alpha DN$$

Where,

A	=	attenuation of one inch thickness of shield material, dB
N	=	number of depth increments in one inch, number
39.37	=	number of inches in one meter
α	=	number of dB of attenuation in a depth increment = 8.64 dB/increment.

The following table contains the results of calculations to determine the attenuation of one-inch thickness of shielding material at 11 GHz.

Material	**Conductivity**	**Penetration Depth**	**Attenuation/inch**
	Mhos/Meter	**Inches**	**dB**
Metals			
Aluminum	$3.5x10^{7}$	$3.2x10^{-5}$	$2.7x10^{5}$
Brass	$1.4x10^{7}$	$5.0x10^{-5}$	$1.7x10^{5}$
Copper	$5.8x10^{7}$	$2.4x10^{-5}$	$3.5x10^{5}$
Lead	$4.5x10^{6}$	$8.9x10^{-5}$	$9.7x10^{4}$
Steel	$9.6x10^{6}$	$6.1x10^{-5}$	$1.4x10^{5}$
Nickel	$1.2x10^{7}$	$5.5x10^{-5}$	$1.6x10^{5}$
Silver	$6.2x10^{7}$	$2.3x10^{-5}$	$3.6x10^{5}$
Zinc	$1.7x10^{7}$	$4.6x10^{-5}$	$1.9x10^{5}$
Others			
Soil	2.0	$1.3x10^{-1}$	64.7
Sea-water	20	$4.2x10^{-2}$	205
Concrete	$6.0x10^{-2}$	$7.7x10^{-1}$	11.2
Carbon	$3.3x10^{4}$	2.7	3.1

As can be seen from the table, the most opaque materials for RF at 11 GHz are metals with only small thickness of metal material required to get high orders of magnitude of attenuation. The drawback to using metal shields is the high level of reflections that are created by these shields. These reflections can unexpectedly find pathways into the site that is being shielded. For other materials, the attenuation is more modest, but when the structures to support them are taken into account along with the thickness required to give the material strength, the attenuation can be within the range required to give the site its desired protection. These non-metallic materials also have the other advantages of not being highly reflective and they diffuse and absorb the RF energy much more effectively than the metal shields. The most effective use of these materials for shielding is to use them in combination; one that takes advantage of the extreme opaqueness of metals and the absorption, diffusion and non reflective qualities of the other materials.

If a mesh (screen) metallic material is used as the shield, the attenuation of the material approximates the attenuation of solid material if the size of the sides of the openings is less than 0.1λ. A wavelength at 11 GHz is 1.07 inches. Therefore, a 1/8-inch screen would not provide equivalent attenuation, but a 1/16-inch screen will.

3.5 Shielding and Knife-Edge Diffraction

Knife-edge diffraction is the main mechanism that limits the effectiveness of shielding at satellite earth station sites. The shielding structures are designed and built to prevent the undesired RF signals a direct path to the site antennnas while allowing the satellite antennas at the site a direct unobstructed view to all of their associated satellites. Knife-edge diffraction allows the undesired RF signals go over and around the shield structures bending the signal into the site.

SkyBridge Gateway earth station antennas may require shielding from any azimuth down to elevation angles of 6° in order to have the ability to communicate with each of their NGSO satellites. This means that the separation of the antennas to the shielding wall of a height of 20.6 feet must be at least 140 feet. Knife-edge diffraction is a function of multiple site and antenna parameters, many of which are not independent of each other. The antenna parameters are frequency of operation, size, site position, pointing angle and illumination characteristic. The site characteristics are the height of the shield, azimuth coverage, material content, and edge treatments.

National Bureau of Standards (NBS) Technical Note 101 provides a method for the calculation of knife-edge diffraction. The method has gained wide acceptance throughout the frequency coordination community. While the wide acceptance applies to the use of the method for those obstructions in the far field of the antennas in question, some coordinators do not feel the method can be applied within the near field region of the antennas in question. Their position is that the method is based on the Fresnel-Kirchoff diffraction theory for light waves in the far field and therefore should only be applied to far field conditions. The far field of an antenna only applies to the antenna's main beam or that volume that is a cylindrical projection with the area or the antenna being the base of the cylinder. Outside of this volume, the far field distance from the antenna is very small. Therefore, the shielding treatment at an earth station site can be considered in the far field of the antennas there and the method of Technical Note 101 may be used for calculating the diffraction attenuation of the shield if applied correctly.

Early on, the approach for evaluating RF shielding effectiveness was to make a single knife-edge diffraction loss calculation from the knife-edge formed by the shield to the vertex of the satellite antenna. Shielding levels consistently fell short of these calculations when the earth station antennas were installed at the site. Numerous measurement projects were performed to investigate this condition and the National Spectrum Managers Association (NSMA) formed a working-group (WG-6) to determine why interference levels exceeded those predicted for the site by the calculations. The measurements using test antennas revealed that the shielding was a function of height, with the highest levels of interference signal, or the greatest effect of knife-edge diffraction, occurring at the highest sections of the earth station antenna. Because of these measurement results, a new method of calculating the effectiveness of a shield was developed under the auspices of the NSMA.

This method uses the NBS Technical Note 101 method but it separates the knife-edge diffraction into a series of vertical rays. These rays will be captured by vertical segments of the earth station antenna. The upper antenna segments of the earth station antenna will intercept the highest levels of interference signal. The upper rim of the antenna is the reference point for the distance to the diffracting shield and the antenna can be divided into 10 or more segments. The greater the number of segments the more accurate the calculation. For each ray, the level of attenuation is predicted for that distance to the top of each segment and for the segment width formed by the size of the antenna segment. In addition, the intensity of the signal intercepted for each ray is a function of the knife-edge diffraction, the antenna illumination characteristic (taper) and the weighting of each antenna segment.

The calculation of the knife-edge diffraction uses the following five formulas and the knife-edge diffraction curve of Technical Note 101.

$$V_n = sign(\Delta H_n) \cdot \sqrt{\frac{2 \cdot |\Delta H_n| \cdot \theta_n}{\lambda}}$$

$$W = -10\log_{10}(N)$$

$$K_n = A(V)_n - T_n - W$$

$$I_n = 10^{\frac{-K_n}{10}}$$

$$A = 10\log_{10}\left(\sum_{i=1}^{N} I_n\right)$$

Where,

V_n	=	function of the ray attenuation and has the sign of ΔH_n
ΔH_n	=	height differential of the antenna segment between the reference formed by the line connecting the top of the shield and the top of the antenna. Heights above are negative and those below positive. The height is always taken to the top of the segment, meters
θ_n	=	radian measure of the angle from the reference point to the top of the segment
λ	=	wavelength, meters
N	=	number of antenna segments
W	=	weighting factor for antenna segments, dB; if 10 segments -10 dB, if 20

		segments -13 dB
$A(V)_n$	=	attenuation of ray due to knife-edge diffraction as a function of V, taken from Figure 7.1 of NBS Technical Note 101, dB
T_n	=	antenna segment illumination factor, dB; if logarithmic -10, -8.1, -6.4, -4.9, -2.5, -1.6, -0.9, -0.4, -0.1, 0, -0.1 etc.
K_n	=	total ray attenuation of antenna segment n as a function of A(v), antenna illumination and segment weighting, dB
Σ (I)	=	numerical summation of all of the ray attenuations with respect to the antenna, number
A	=	cumulative attenuation as a result of knife-edge diffraction, dB.

If the shield is constructed of the proper material, the only interference signal of concern is that entering the site via the knife-edge diffraction mechanism. Calculations were performed to determine what attenuation levels to expect for various shield heights and separation distances of the antennas and the wall. For the calculations, the antenna was divided into 20 segments, and a logarithmic illumination taper was assumed. In order for the antennas to have a minimum unobstructed elevation angle of 6°, the 4.5-meter antenna needed a 42.6-meter separation distance to the wall, and the 2.5-meter antennas needed a 23.8-meter separation distance to the wall.

Calculations were performed using an Excel spreadsheet format for the various site configurations. The conditions for the calculations and the shielding results are shown in the following table.

Shielding Calculated	**Antenna Diameter**	**Distance**	**Elevation**	**Square Edge**	**Rounded Edge**
dB	**Meters**	**Meters**	**Degrees**		
20.7	4.5	42.6	6	√	
18.8	4.5	85.2	6	√	
17.6	4.5	127.8	6	√	
23.2	4.5	42.6	45	√	
29.0	4.5	42.6	6		√
19.0	2.5	23.8	6	√	
17.1	2.5	47.6	6	√	
27.5	2.5	23.8	6		√
20.9	2.5	23.8	45	√	

The calculations for knife-edge diffraction were performed for various site conditions to determine technical tradeoffs for various parameters. From the calculations it was determined that as the antennas were moved closer to the wall, the effects of diffraction would be correspondingly diminished. However, the distance to the wall was dictated by the minimum elevation angle of the antenna, which in this case was 6°. If the elevation angle in the direction of the wall could be compromised, then the effects of diffraction could be further reduced. This could be brought about in two ways, either moving the antennas closer to the wall, or raising the wall in height.

An interesting fact was ascertained while performing the knife-edge calculations. The effective shielding for an antenna was a function of the size of the antenna if all other factors for the site were held constant. For instance, the following parameters were used: a minimum elevation angle of 6°, a shield height equal to the top of the antenna when the antenna is at 6° and a separation between the antenna and the shield of the minimum distance to allow unobstructed clearance of the main beam over the shield. The calculations for these parameters showed that larger antennas could be shielded more effectively. The calculation results are summarized in the following table.

Antenna Size	**Minimum Separation to Shield**	**Shielding for 6° Elevation Angle**	**Shielding for 45° Elevation Angle**	**Shield Height**
Meters	**Meters**	**DB**	**dB**	**Feet**
2.0	19.0	18.4	20.1	12.5
2.5	23.8	19.0	20.9	14.1
3.0	28.5	19.5	21.6	15.7
3.5	33.3	20.0	22.2	17.4
4.0	38.1	20.4	22.7	19.0
4.5	42.6	20.7	23.2	20.6
5.0	47.6	21.0	23.6	22.3
5.5	52.4	21.3	24.0	24.0
6.0	57.0	21.5	24.4	25.6
6.5	61.9	21.8	24.7	27.2
7.0	66.6	22.0	25.0	28.9
8.0	76.2	22.4	25.6	32.2
9.0	85.2	22.7	26.1	35.3
10.0	95.2	23.0	26.6	38.7

3.6 Edge Treatments

Treatments to the top of the wall have been used to reduce knife-edge diffraction. They have included creating a multiple (usually two) knife-edge, curving the leading and trailing edge of the top of the wall, and installing RF absorbing material on the top surface of the wall. The multiple knife-edge treatment requires that there be a separation of at least ten wavelengths between the diffracting edges, this is approximately 10 inches at a frequency of 11 GHz. Curving the leading and trailing edge of the wall causes the diffracted signal to take a more tangential path from the shield, thereby causing the RF shadow area behind the shield to be increased. The RF absorbing material at the top of the wall produces a reduced signal to be diffracted from the edge increasing the RF shadow area behind the shield.

Figure 2 shows the top edge treatment of a shielded wall built by FANWALL that it was reported produced an improved shielding of between 3 and 4 dB at C-Band. A calculation performed during this task, using the rounded treatment where ρ is equal to 0.5 and the values of A(V) were taken from Figure 7.3 of NBS Technical Note 101, produced a signal attenuation of 29.7 dB. This value can be compared to an attenuation of 20.7 dB calculated when there is no top edge treatment. Information on improved knife-edge diffraction using RF absorbing material could not be found in the technical literature. Measurements will have to be performed to determine the effectiveness of this method of reducing diffraction effects.

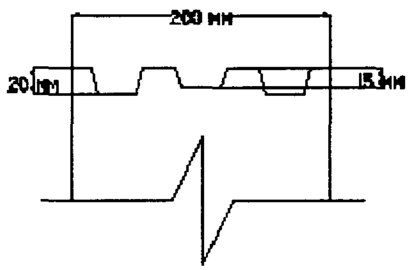


FIGURE 2

EDGE TREATMENT FOR FANWALL SHEILD

4. Shield Testing

There are two types of testing that are recommended for site shielding. The first type will measure the attenuation path through the material and can be performed prior to the installation and again during the site verification tests. This test should be performed over the frequency range of interest 10.7 - 14.5 GHz. The second test will be the site shielding verification test, which in reality is a test of the knife-edge diffraction coupling. This coupling should be greater than or equal to the predicted attenuation due to the shielding for the site. For this experiment, a test antenna of known gain will be mounted on a vertical mast, raised above the shield height and pointed at a known terrestrial interference source in the 11-GHz frequency range. The test antenna output will be connected to a calibrated field intensity meter or spectrum analyzer, and the level will be measured. Next, the test antenna will be pointed at the shielding edge and incrementally moved to duplicate the vertical increment positions used in the calculated prediction of the knife-edge diffraction attenuation. The received signal level for each step will then be measured. These levels will be normalized for the gain of the test antenna versus the incremental gain and weighting of the satellite antenna at each height used in the calculations so that a direct comparison of the diffraction ray calculations and measurements can be made. A measurement of the interference signal level at the satellite antenna waveguide flange when the antenna is pointing in the azimuth of the interference signal will also be performed to compare to the calculations. If the terrestrial interference source does not provide a level that will allow the full range of shielding to be determined, a test signal will be generated via a test antenna outside the shielded area and the experiments will be performed using it as the interference source.

5. Other Factors and Considerations

In addition to meeting the shielding required at each of the SkyBridge Gateway facilities, the structure must be adaptable to resolving interference to and from new sources. Additionally, it must be maintainable at a reasonable effort and within the capability of site operational personnel, it must physically fit within the site dimensions, it must cover the frequency band from 10.7 - 14.5 GHz and it must be acceptable to the general community from an aesthetic standpoint.

Each site will be selected to meet the physical operation requirements for the Gateways. In addition to full sky view coverage for all antennas down to an elevation of 6-degrees, the site selection will examine the presence of other facilities in the 11-GHz band that potentially would be an interference signal source or victim of the gateway operation. Under the best circumstances, no other systems would be present, and no shielding would be necessary in the initial site build. If other systems are found, site measurements can be made to determine the actual signal levels at the site. At the same time, a site survey can be performed to determine the natural and man-made structures that provide the site with shielding. The survey should be performed at various azimuths in addition to the azimuth of the potential problem system, possibly a 45° interval, so that the information would be available if a future terrestrial site had to be coordinated. If the site measurement levels revealed that no threat to or from site operations was present, no shielding would be necessary. However, if the measurements did reveal a problem level, then the shielding would need to be included in the initial site construction if an alternative location could not be obtained or would be acceptable for that service area.

Shielding must be of a form that can be added to a Gateway site that did not have it initially installed or to one that had shielding installed but needs protection from signals along another azimuth. This capability of adding shielding or modifying existing shielding is very important for the shielding treatment selected for the SkyBridge Gateway sites.

The shielding treatments considered for the Gateway sites cover the frequency range of interest, 10.7 - 14.5 GHz.

One non-technical issue that cannot be overlooked is the aesthetics of the site and its shielding and how they affect the community. From the beginning of site acquisition, the community sensitivities on site design should be taken into account. A person representing the site should be actively involved at the appropriate governmental and business organizations so that questions and opinions from the community can be responded to before problems develop. If special aesthetic treatments are needed to satisfy the community, the monetary and time investment in pacifying the community and being viewed as a "good neighbor" can be well worth the hassle. For example, if down the line someone wants to install a grain silo, water tower, or any other structure close to the Gateway site that may create reflections that may compromise the shielding treatment of the site a more sympathetic hearing to objections to the new structures will be likely if good relations have been established.

Effective grounding of the shielding treatment is extremely important. The wall should be grounded at each support member. Metal panels or mesh used for the shield should be bonded to the grounding rods installed at each support member. The facility ground system should tie the grounding of the antennas and the shielding together.

Maintenance of the site shielding treatment should be routine and simple. Preventative maintenance routines should be designed to visually examine the shield and report any physical damage, weathering or corrosion buildup. Simple material restoration or cleaning should be the only activities required by site personnel.

The site selection effort and subsequent site planning should take into account the requirement of the initial or future need to install shielding at the site. Enough space should be allowed so that the shielding can be positioned 140 feet from the 4.5-meter dishes and 78 feet from the 2.5-meter antennas to allow the 6° minimum unobstructed elevation angle. Overall site dimensions should take this need into account during property acquisition.

6. Cost Analysis

The cost of the shielding structure for a SkyBridge Gateway facility can vary over a wide range. Estimates obtained from various contractors and vendors put the cost anywhere from $50 thousand to over $1 million. Cost and shield effectiveness is not a directly proportional relationship; higher cost of the shielding treatment does not necessarily produce better isolation after a certain level of shielding has been reached. The cost of the shield is directly a function of the material to be used and the labor needed for construction. Shielding treatments using reinforced concrete will not produce better shielding than a properly designed mesh structure. Appearance factors may add cost and may be necessary for zoning board approval, but they will not add to the shield performance. Maintenance costs for the various shielding treatments will be low over the facility's lifetime. Flexibility and cost of adding to a shielding treatment because of facility expansion or the threat of interference to or from a new azimuth is definitely better for the low cost treatments.

In order to obtain comparable cost estimates, a number of contractors and vendors were asked to provide budgetary estimates to produce a shield wall of 1000 linear feet and a height of 20 feet 8 inches anywhere in the United States. The results of the estimates were:

Wall Description	Cost/Square Foot	Total Cost
Composite Wall—Concrete/Metal Built on four-foot Berm with Solid Foundation	$100.00	$2,000,000
Concrete Panel Wall—Built on Gravel Foundation within four-foot Trench	$25.00	$500,000
Metal Panel Wall—Built on Gravel Foundation within four-foot Trench	$15.00	$300,000
Chain Link Fence Supporting Mesh Material	$10.25	$205,000
Mesh Wall Supported by Telephone Poles		
Single Thickness	$2.33	$46,620
Double Thickness	$4.22	$84,420

The least costly shield is the flexible mesh installed between telephone poles or on a chain link fence. The low cost of this treatment is attributed to mass production of the material, low cost of shipping it and the minimal cost of installing the mesh screen. Another advantage of this type of installation is that it is easy to modify or expand. Maintenance costs are low, and the open nature of the material provides a site visual openness. The disadvantage is one of appearance, which may be unacceptable in some areas. However, the appearance issue may apply equally to all shielding treatments.

Medium cost shielding can be achieved with metal or concrete panels. Maintenance of this type of shielding is low; however, rust proofing of the metal panels will be required. In some areas, such as adjacent to the ocean, this may be an ongoing action. Modification or expansion of the shielded area is normally not a problem as the concrete or metal panels are normally movable and interchangeable, and the entire structure is expandable. Concrete panels, which have proven to be less objectionable to the general population than metal panels, are cast on-site to reduce shipping cost.

Composite walls of concrete, metal and berm are high cost. They do not lend themselves to flexible modification or expansion because of the complex nature of their structure. Because of these factors, they may not be as desirable for application in the SkyBridge Gateway facilities.

Shielding from berms or pits is of questionable application for earth station antennas that are tracking NGSO satellites. Their application for GSO tracking antennas often limits full arc coverage. Also, their cost is even higher than the composite walls and the flexibility to modify or expand is very limited.

7. Conclusions

Shielding in the range of 20 dB can be constructed at the SkyBridge facilities. This can be achieved with a shield wall constructed of material that will attenuate the signals by a combination of reflection, absorption and diffusion. This wall should be at the same height as the top of the antennas when they are at a minimum elevation angle of 6° and at a distance from the antennas of 140 feet for the 4.5-meter antennas and 78 feet for the 2.5-meter antennas.

The shielding of a site does not necessarily rely solely on the site shielding treatment; it can also benefit from natural and man-made objects along the interference path that will increase the attenuation factor. For example, if an interference condition is predicted, a site survey and precise path profile might show hills, trees, buildings and other obstructions in the path that will produce additional attenuation. This attenuation adds directly to the site shielding that has been created at the site. If path factors produce attenuation of 10 dB and site shielding is 20 dB, the net effect for that interference path will be 30 dB.

Diffraction over and around a shield constructed of the proper material is the limiting mechanism of site shielding. Attenuation of signals directed at and through the shield is many orders of magnitude greater than the signal that is diffracted over and around it. This has been demonstrated both theoretically and by measurements in countless studies and projects. Diffraction is a function of the geometric position of the shield and antennas. The diffracted signal is higher when the antennas are at a small angle relative to the edge of the shield. Since this angle decreases with increasing separation distance between the shield and wall, the separation distance also affects the diffraction levels.

The other factor that limits effectiveness of a shielded site is that of tall structures which cause reflections that enter a site from angles above the shield. Additionally, in a totally enclosed site, signals that diffract over the wall can be reflected by the inside surfaces of the wall and can cause interference problems. To establish that the shielding for the SkyBridge Gateway sites will not be compromised by reflections, the site surveyors should examine the surrounding area for reflective structures before the site acquisition decision is made. If such structures are present, it could potentially disqualify the property as a Gateway site. After the site is built, any plans brought before the area's governmental jurisdiction body on planning and growth to build a structure that could cause reflections into the site should be contested on the grounds that it would be detrimental to the operation of the site. The plan for shielding at the Gateway sites is to shield in one direction and not enclose the site. This eliminates the problem of reflection of diffracted signals that may cause reflections within the site. If the site were enclosed, treating the inside walls with RF-absorbing material would be a method of dealing with reflections from the inside walls.

The importance of including RF evaluations and site surveys in the initial site selection process is crucial and must not be overlooked. The capability of selecting a site that will require no shielding is preferable to one that will initially require shielding. Enough property should be included so that shielding can be included, whether or not it is initially necessary. If shielding is not required preliminarily, it may still be required in the future, so it is imperative that space be secured for a shield.

Sites that have tall structures close by should be avoided because of the possibility of reflections. RF evaluations of a site should be made by both an interference analyses based on database information and RF measurements supported by the interference analysis at the site. These should be combined with site surveys out to a distance of 10 kilometers at each 45° azimuth for each site being considered for acquisition.

In order to accommodate a new coordination, if more shielding is required for a site that may or may not already have shielding present, it may also be necessary to reconfigure the deployment of the antennas at the site. This requirement is due to the fact that the shielding of any one antenna is a function of its position with respect to the shield. An evaluation of the antenna configuration with respect to the shield will be necessary to determine this possibility. In addition to the cost of the shield, there may be the additional cost of the antenna relocation and the downtime for the site.

If the site is constructed with shielding, measurements of the shielding effectiveness should be performed as soon as construction is complete. The measurement results should be compared to the shielding predictions. Any discrepancies should be investigated, corrected and explained as necessary.

The study revealed that larger antennas are more effectively shielded than smaller ones. However, there is a cost consequence of this. Larger antennas are more costly. The shielding must be taller and the separation distances between the antennas and the shield, and between the antennas themselves must be greater resulting in a larger site requirement. These factors will increase cost. Some offset to this may result from a reduced transmitted power requirement for the same link budget because of the larger antennas

Non-standard methods of shielding or unusual edge treatments do not seem to be the type of approach that should be recommended for the Gateway sites. Antennas equipped with shielded and movable radomes have never been built before, and therefore the engineering development costs would make them prohibitively expensive. The same would apply to electronically directive conformal antennas. Edge treatments used in the past have provided some shielding improvement; however, the majority of structures considered for the Gateway sites do not physically permit edge treatments. An exception involves the use of concrete panels where the improvement has been on the order of 3 to 4 dB. Also, the chain link fence with the "V"-shaped structure at the top, which normally supports barbed wire, could serve as a double knife-edge. It would provide additional attenuation, but its effect would have to be measured. No information could be found on the use of microwave absorbing material as an edge treatment.

Two shielding projects were dealt with at COMSEARCH during the preparation of this study that have a direct bearing on the shielding issues at the Gateway sites. In the first, a company wanted to install a C-Band geo-stationary satellite earth station at a site in New Mexico that was directly in the path of a terrestrial microwave link. The interference analysis for the site showed that the case from the North was 46 dB and the one from the South was 36 dB. COMSEARCH recommended that another site be selected because shielding could not be expected to eliminate the entire interference signal especially from the south which was the direction of the satellite arc clearance. In the second case, a company had installed a shield at a location in Mexico City which was not providing the expected shielding to local interference signals. Analysis of the shield construction revealed four problem areas; the mesh material used had an opening of a quarter wavelength, the mesh did not extend all the way to the ground, the mesh was not overlapped at the support poles, and only one of the 10 support poles was grounded and its ground was not tied into the site ground system. When these areas were corrected the site shield provided the expected isolation.

8. Recommendations

To address the shielding requirements for the SkyBridge Gateway Sites, the following steps should be taken:

1) Every site considered for acquisition should undergo an interference analysis and on-site measurements.

2) Site surveys at 45° intervals out to a distance of 10 kilometers should be performed and made part of the on-site data package. This will evaluate potential natural shielding that may be used to augment the on-site shielding to be constructed. Arc clearance down to 6° at all azimuths should be verified.

3) If shielding for the site is required, an engineer who understands the site shielding requirements should monitor its installation. He will specifically examine the adequacy of the shielding with respect to its:
    a) Physical dimensions and features
    b) Proper grounding

c) Relative distance to all site antennas
d) Make sure that aesthetic issues for the shielding are present
e) Arrange and participate in the shielding proof-of-performance measurements

4) Shielding proof-of-performance testing should be performed after the shielding is constructed. The measured data should be compared to the predicted levels. If inadequacies in the shielding are identified, corrective actions should be taken immediately. A copy of the measured data should remain on site for future reference and for quality control monitoring of the shielding over the life of the site.

5) The Gateway site engineer should establish a good working relationship with the appropriate governmental planning body for the site's jurisdiction. Therefore, if any construction in the area is planned that could cause reflections into the site, the engineer he should be aware of it and take the opportunity to raise early objections to the construction and recommend alternatives. His effectiveness with the planning board and the community in general is vital to keeping the site free of reflections from local structures.

APPENDIX A

The following is a list of the Publications, Technical Notes and Reports used in the preparation of this report.

1. COMSEARCH, Contract INTEL-718, "Interference Prediction and Reduction Techniques for Small Earth Stations," September 1989.

2. Bornkast, Horst, "Interference Control for Earth Stations," GTE Spacenet corporation, August 1991.

3. National Bureau of Standards--Technical Note 101, "Transmision Loss prediction for Tropospheric Communication Circuits," Volume I, January 1967.

4. COMSEARCH, "Radio frequency Interference (RFI) Measurement Report -- IDB Los Angeles Transmit/Receive Earth Station," September 1992.

5. Spectrum Planning, "Field engineering Report of Radio Frequency Interference Performed at Columbus, Ohio," May 1986.

6. National Spectrum Managers Association (NSMA), "Earth Station Shielding Recommendation --Working Group 6," April 1989.

7. Jasik, Henry, "Antenna engineering Handbook," McGraw-Hill, 1961.

8. Valkenburg, Van, "Reference Data for Engineers: Radio, Electronics, Computer, and Communications- Eighth Edition," Prentice Hall, 1993.

9. Scheeren P., "Reduction of Transhorizon Radio Interference in Satellite Earth Stations," Eindhoven University of Technology, October 1988, (Ph,D. Dissertation).

10. Lucia, E., "Artificial Site Shielding for Communications Satellite Earth Stations," IEEE Transactions of Areospace and Electronic systems, Vol. AES-6 No. 5 pp 251-253, September 1970.

11. FANWALL, "FANWALL RFI Shield for MCI Satellite Earth Station, Hayward, California," 1984.

12. Kizer, George, "Microwave communication," Iowa State University Press/Ames, 1990.

13. Tocci, George, "Practical Applications of Precast Concrete Noise control Barriers," NOISE EXPO, National Noise and Vibrational Control Conference, March, 1978.

14. List of Past COMSEARCH Shielding Projects Referred to in this Project:

1) Design of RF Shield for C-Band Earth Station for CBS in Sacramento, California;
2) Design of RF Shield Made of Free Standing Concrete Panels for Multiple C-Band antennas at ABC Facility, Omaha, Nebraska;
3) Small RF Screens for small Earth Station Antennas for Equatorial, Mountain View, California;
4) Testing of Various Concrete Walls for C-Band Earth Stations, San Antonio, Texas;
5) Testing of Perforated Aluminum Earth Station Shield for IBM Transmit/Receive System, Southfield, Michigan;
6) Contributing Members of National Spectrum Managers Association, Working Group - 6, Which Dealt with the Design, Testing and Evaluation of Earth Station Shielding.

15. FCC Application, "SkyBridge L.C.C. Application to launch and Operate the SkyBridge Satellite System," 48-SAT-P/LA-97, February 28, 1997.

16. FCC Application Amendment(1) , "SkyBridge L.C.C. Application to launch and Operate the SkyBridge Satellite System," 89-SAT-AMEND-97.

17. FCC Application Amendment(2), "SkyBridge L.C.C. Application to launch and Operate the SkyBridge Satellite System," June 30, 1998.

18. COMSEARCH, "Radio Frequency Interference (RFI) Inter-System Testing – Keystone Inspirational Network, Red Lion, Pennsylvania, Transmit/Receive Earth Station," November 1991.

E

APPENDIX E

Protection of TDRSS by NGSO FSS Systems

The 13.75 – 13.8 GHz band, which has been allocated to NGSO FSS systems at WRC-97, is a reception band for the space shuttle that communicates with the TDRSS satellite network. This appendix accesses the level of interference generated by SkyBridge operation in this band into the shuttle receiver.

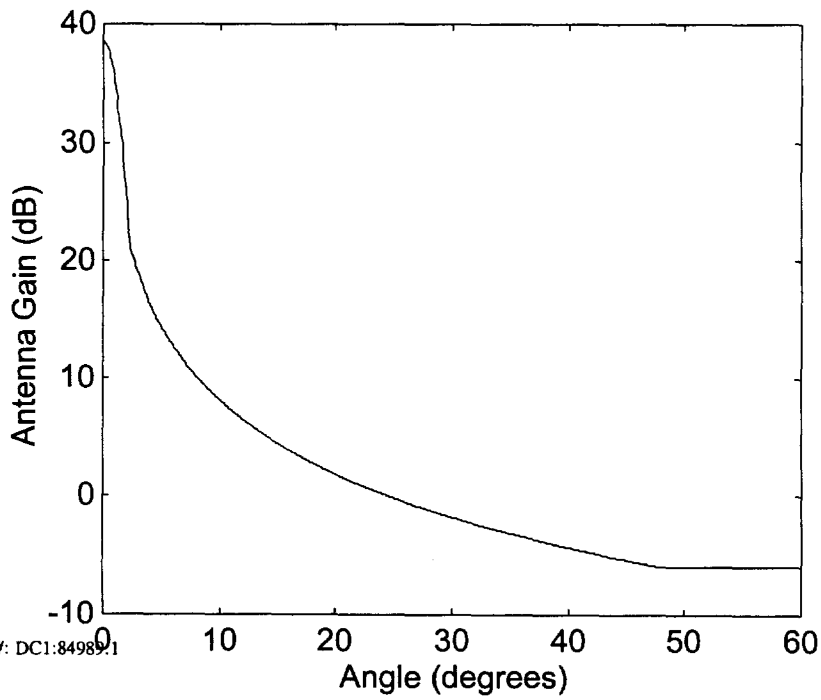
The orbital characteristics of the shuttle and TDRSS network are shown in Table 1.

Table 1
Orbital Characteristics of Space Shuttle/TDRSS Network

Constellation Characteristics	Space Shuttle	Relay Satellite
System type	NGSO	GSO
Orbit height	300 km	gso radius
Period	90.5 min	24 hrs
Number of planes	1	1
Inclination Angle	51.6°	0°
Satellites per plane	1	5
Plane Spacing	n/a	41 W, 46 W, 174 W, 177 W, 85 E

The space shuttle receiver antenna gain is shown in Figure 1 (see Document 4-9-11/130).

Figure 1
Space Shuttle Receive Antenna Gain



The space shuttle receiver noise temperature is assumed to be 120 K. The interference threshold for the space shuttle, specified in ITU-R SA 1155, is –140.2 dBW per 6 MHz.

The characteristics of the SkyBridge system are shown in Table 2.

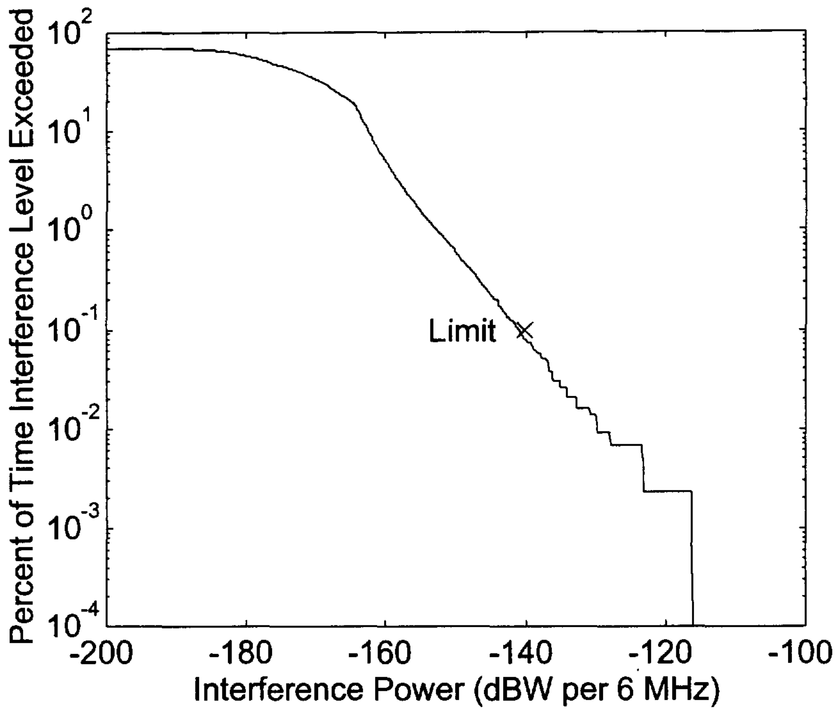
Table 2
SkyBridge System Characteristics

System Characteristics	SkyBridge
Constellation	
System type	NGSO
Orbit height	1469 km
Period	115 mins
Number of planes	20
Inclination Angle	53°
Satellites per plane	4
Plane Spacing	18°
Satellite phasing between planes	67.5°
Minimum elevation angle	10°
GSO arc avoidance angle	10°
RF Parameters	
Frequency	14 GHz
Earth station transmit EIRP	68 dBW
Earth station transmit antenna peak gain	53.8 dBi
Earth station transmit antenna gain pattern	Rec. 465
Bandwidth	22.6 MHz
Tracking strategy	Highest elevation
Tracking conditions	Elevation>10, GSO>10
Maximum number of space station beams	12
Transmit antenna footprint diameter	700 km
Number of earth cells modeled	426

A total of 426 gateway cells are modeled to cover all land masses (although SkyBridge anticipates deploying only about 200 gateways worldwide). For gateway cells located between 37° N and 50° N, three transmitting antennas per gateway cell are assumed. For all other gateway cells, one transmitting antenna is assumed. All gateway antennas transmit with an EIRP of 68 dBW in 22.6 MHz.

A computer simulation was used to determine the cumulative distribution function of the interference power into the space shuttle receiver. The results are plotted in Figure 2.

Figure 2
SkyBridge Gateway Uplinks into Space Shuttle Receiver



Even with the worst case assumptions made here, the SkyBridge system meets the interference criteria for the space shuttle receiver.

The JTG 4-9-11 recently discussed sharing issues in the 13.75 – 14 GHz band. Several options were considered, including replacing the minimum EIRP limit in ITU Radio Regulation footnote S5.502 with language that would not allow the FSS to claim protection from the radiolocation and radionavigation services.[1] Reduction or elimination of the EIRP requirement would further ensure protection of the TDRSS downlinks to the space shuttle.

[1] Document 4-9-11/TEMP/48 (Long Beach).